BRUNA LORENA PEREIRA MORO

Evaluation of two visual criteria on diagnosis and treatment decisions of caries lesions around restorations

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e por darem todas as condições possíveis
para que eu vá em busca dos meus sonhos.

"Quando as raízes são profundas, não há razão para temer o vento"

Provérbio Chinês

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ABSTRACT

Moro BLP. Evaluation of two visual criteria on diagnosis and treatment decisions of caries lesions around restorations [thesis]. São Paulo: University of São Paulo, Faculty of Dentistry; 2021. Original Version.

This research aims to evaluate the effect of using two visual criteria on diagnosis and treatment decisions of caries lesions around restorations, focusing on clinical studies in primary teeth. The selected criteria were the International Dental Federation (FDI) criteria and the Caries Associated with Restorations and Sealants (CARS) system. For the FDI criteria, the subcategories marginal staining, marginal adaptation, and recurrence of caries were used. For the CARS system, a proposed treatment decision was used in association with the criteria. This thesis presents a compilation of studies related to this subject, being (I) a study protocol of a randomized clinical trial (RCT) to evaluate restorations in children, (II) a cross-sectional study to compare treatment decisions, (III) a delayed type cross-sectional prospective accuracy study in primary teeth, and (IV) an in vitro study using the criteria in permanent teeth. The RCT (I) objective, which is the main study, was to evaluate the effect of two visual criteria in the assessment of 626 restorations in primary teeth in a sample of children from three to 10 years old. The primary outcome will be the need for a new intervention in the evaluated restorations after two years of follow-up. The changes in children's oral health-related quality of life and the restorative dental treatment cost will also be analyzed as secondary outcomes. The cross-sectional study (II) aimed to investigate the influence of the FDI and CARS system on the decision to replace 550 restorations in primary posterior teeth in the same sample of children of the study (I). Variables that might influence this decision were also considered. The delayed type cross-sectional prospective accuracy study evaluated the sensibility, specificity, and accuracy of the FDI and CARS system in detecting caries lesions around 651 restorations in primary teeth in the same sample of children of the study (I). The reference standard methods were the restoration removal and visual-tactile examination of dentin beneath the margin interface when the replacement was indicated or visual-tactile detection and assessment of the restoration after six and 12 months of follow-up. An in vitro study (IV) was also carried out in a sample of 116 composite restorations of permanent posterior teeth. This study aimed to evaluate

the FDI, CARS, and three-dimensional (3D) intraoral scanner's performance in detecting secondary caries lesions and predicting their severity. The reference standard was the histological examination. It was observed that restorations evaluated according to the FDI criteria were more frequently indicated for replacement than those assessed with the CARS system. Besides that, children's caries experience and multisurface restorations influenced the decision to replace restorations. Regarding the accuracy of the methods, the CARS system was more accurate than the FDI criteria. However, the FDI criteria for evaluating recurrence of caries and marginal adaptation presented similar performance to the CARS system when the dentin threshold is considered. On the other hand, marginal staining was not an accurate parameter to evaluate caries around restorations in primary teeth. In a sample of permanent teeth, both visual criteria are moderately correlated with lesion depth. The 3D intraoral scanner does not add further information to gap size assessment than visual inspection. In conclusion, the CARS system seems to be the most accurate diagnostic visual method and suggests less invasive treatment decisions than FDI criteria. However, the FDI recurrence of caries is similar to the CARS system. The marginal staining definitely should not be used to evaluate caries lesion around restorations or to indicate restoration replacement.

Keywords: Dental Caries. Diagnosis. Dental Restoration Failure. Dental Restoration Repair. Clinical Study.

RESUMO

Moro BLP. Avaliação de dois critérios visuais no diagnóstico e decisões de tratamento de lesões de cárie ao redor de restaurações [tese]. São Paulo: Universidade de São Paulo, Faculdade de Odontologia; 2021. Versão Original.

O objetivo desta pesquisa foi avaliar o efeito do uso de dois critérios visuais no diagnóstico e decisões de tratamento de lesões de cárie ao redor de restaurações, dando ênfase à realização de estudos clínicos em dentes decíduos. Os critérios utilizados foram o sistema proposto pela Federação Dentária Internacional (FDI), composto pelos parâmetros manchamento marginal, adaptação marginal e recorrência de cárie, e o Caries Associated with Restorations and Sealants (CARS) associado a uma proposta de decisão de tratamento para ser utilizada em associação ao critério. A presente tese contém um compilado de estudos relacionados a esse tópico, sendo (I) o protocolo de um ensaio clínico randomizado (ECR) de avaliação de restaurações em crianças, (II) um estudo transversal comparando decisões de tratamento, (III) um estudo de acurácia diagnóstica com desfecho tardio em dentes decíduos e (IV) um estudo in vitro utilizando os métodos em dentes permanentes. O objetivo do ECR (I), que é o estudo principal, foi avaliar o efeito dos dois critérios visuais na avaliação de 626 restaurações em dentes decíduos, numa amostra de crianças de 3 a 10 anos, considerando desfechos relacionado com a saúde oral de crianças e com os custos relacionado as avaliações após dois anos de acompanhamento. O desfecho primário será a necessidade de uma nova intervenção na restauração avaliada após 2 anos de acompanhamento. Mudanças na qualidade de vida das crianças após dois anos, assim como os custos e efeitos dos tratamentos por criança, serão analisados como desfechos secundários. O estudo transversal (II) teve como objetivo investigar a influência dos critérios FDI e CARS na avaliação de 550 restaurações em dentes decíduos na decisão de substituição das restaurações na mesma amostra de crianças do estudo (I). Outras variáveis que possivelmente poderiam influenciar esta decisão de tratamento também foram consideradas nas análises. No estudo de diagnóstico com desfecho tardio (III) foram avaliadas a sensibilidade, especificidade e acurácia dos critérios FDI e CARS na detecção de lesões de cárie ao redor de 651 restaurações

em dentes decíduos, na mesma amostra de crianças do estudo (I). O padrão de referência utilizado foi a avaliação visual-tátil da dentina abaixo da restauração quando indicada a substituição na linha de base ou o exame visual-tátil da restauração após 6 e 12 meses de acompanhamento. Um estudo in vitro (IV) também foi realizado numa amostra de 116 dentes permanentes posteriores restaurados com resina composta, com o objetivo de avaliar a performance dos métodos FDI, CARS e do scanner 3D na detecção de lesões de cárie secundárias e na predição de severidade das lesões. O padrão de referência utilizado neste estudo foi a avaliação histológica. Observou-se que restaurações avaliadas pelo critério FDI receberam maior número de indicações de substituição comparadas as avaliadas pelo critério CARS. Além disso, a experiência de cárie da criança e restaurações multisuperfície influenciaram a decisão de substituição. Em relação a acurácia dos métodos, o CARS apresentou maior acurácia que o critério FDI, mas os parâmetros de avaliação da adaptação marginal e cárie recorrente propostos pelo FDI apresentaram performance similar ao CARS quando o limiar da dentina foi considerado nas análises. No entanto, o manchamento não se mostrou um parâmetro acurado para detectar lesões de cárie ao redor de restaurações em dentes decíduos. Quando avaliados in vitro numa amostra de dentes permanentes, os dois critérios visuais mostram uma correlação moderada com a profundidade das lesões de cárie ao redor de restaurações de dentes permanentes, e o scanner 3D não melhora a avaliação de falhas marginais das restaurações, comparado com o exame visual. Em conclusão, o CARS parece ser um sistema mais acurado e que leva a intervenções operatórias menos invasivas do que o FDI. No entanto, o critério de avaliação de recidiva de cárie do FDI é semelhante ao CARS. A avaliação do manchamento definitivamente não deve ser utilizado como um parâmetro para determinar a presença de lesão de cárie ou para indicar a troca das restaurações.

Palavras-chave: Cárie Dentária. Diagnóstico. Falha de Restauração Dentária. Reparação de Restauração Dentária. Estudo Clínico.

LIST OF ABBREVIATIONS AND ACRONYMS

3D	Three-dimensional
95%CI	95% confidence interval
A.R.B.	Ana Raquel Benetti
BLPM	Bruna Lorena Pereira Moro
CaCIA	Caries Cognition and Identification in Adults
CAPES	Coordination for the Improvement of Higher Education Personnel
CARDEC-03	CARies DEtection in Children n° 3
CARS	Caries Associated with Restorations and Sealants
CNPq	National Council for Scientific and Technological Development
D.P.R.	Daniela Prócida Raggio
DMF-T	Decayed, missing, and filled teeth permanent teeth
dmf-t	Decayed, missed and filled primary teeth
ECOHIS	Early Childhood Oral Health Impact Scale
ECR	Ensaio clínico randomizado
FAPESP	São Paulo Research Foundation
FDI	International Dental Federation
FMM	Fausto Medeiros Mendes
FOUSP	University of São Paulo School of Dentistry
H.C.M.M.	Haline Cunha de Medeiros Maia
ICCMS	International Caries Classification and Management System
ICDAS	International Caries Detection and Assessment System
J.C.P.I.	José Carlos Pettorossi Imparato
K.R.E.	Kim Rud Ekstrand
LRAP	Laura Regina Antunes Pontes
M.M.B.	Mariana Minatel Braga
M.S.C.	Maximiliano Sérgio Cenci
Ppm	Parts per million
PR	Prevalence Ratio
R.D.F.	Raíza Dias de Freitas
RCT	Randomized clinical trial
Rho	Spearman’s correlation coefficient

S.M.	Stavroula Michou
SPIRIT	Standard Protocol Items: Recommendations for Interventional Trials
STARD	Standards for Reporting Diagnostic Accuracy Studies
STROBE	STrengthening the Reporting of OBservational studies in Epidemiology
T.L.L.	Tathiane Larissa Lenzi
TKT	Tamara Kerber Tedesco

PREFACE

Four chapters compose the present thesis in chronological order of its development. Three chapters (I, II, and III) were focused on clinical studies performed to evaluate restorations in primary teeth. These studies are nested in a randomized clinical trial named CARies DEtection in Children n° 3 (CARDEC-03). The trial was designed to investigate the effect of two clinical criteria in assessing caries lesions around restorations in children. The study was registered on Clinicaltrials.gov (NCT03520309) on 9 May 2018. The local ethics committee from the School of Dentistry of the University of São Paulo approved the study (registration no. 2.291.642) on 22 September 2017 (Attachment A). The main clinical trial was carried out at the University of São Paulo and was supported by the São Paulo Research Foundation (FAPESP; Grant # 2017/22897-3) and by the National Council for Scientific and Technological Development (CNPq; Grant # 141425/2017-2). The last chapter (IV) is a study developed at the University of Copenhagen as part of an exchange program supported by the São Paulo Research Foundation (FAPESP; Grant # 2019/21760-0).

Chapters I and II are published in international journals. The pre-proof version of these two manuscripts is presented in this thesis. Chapter III and IV are being reviewed by the co-authors and will be submitted for publication soon.

I. Moro BLP, Signori C, Freitas RD, Pontes LRA, Lenzi TL, Tedesco TK, Raggio DP, Braga MM, Ekstrand KR, Cenci MS, Mendes FM; CARDEC collaborative group; CaCIA collaborative group. The effect of two clinical criteria in the assessment of caries lesions around restorations in children (CARDEC-03): study protocol for a diagnostic randomized clinical trial. F1000Res. 2020 Jun 26;9:650. doi: 10.12688/f1000research.23801.2.

II. Moro BLP, Freitas RD, Pontes LRA, Pássaro AL, Lenzi TL, Tedesco TK, Ekstrand KR, Braga MM, Raggio DP, Cenci MS, Mendes FM. Influence of different clinical criteria on the decision to replace restorations in primary teeth. J Dent. 2020 Oct;101:103421. doi: 10.1016/j.jdent.2020.103421.

III. Clinical performance of CARS system and FDI criteria in detecting secondary caries lesions in primary teeth

IV. In vitro performance of three-dimensional intraoral scanner and two visual criteria in detecting caries around composite restorations

CONTENTS

1 INTRODUCTION

Dental caries is still one of the most prevalent chronic diseases in the world (1). Several accuracy studies have been carried out on different methods for detecting primary caries lesions in primary and permanent teeth (2-4). However, the detection of caries lesions around restorations has been much less investigated, which can be seen in the quantity and quality of published studies (5, 6).

Caries around restoration is often called "secondary caries" or "recurrent caries" (7). Nevertheless, its pathogenesis follows the same concept of any caries lesion, involving demineralization and enzymatic dissolution of dentin's organic component (8). These lesions have been traditionally associated with defective restorations, mainly gaps between the tooth and the restoration, allowing biofilm to enter the interface (9, 10). However, increasing evidence indicates that the lesion around restoration could not necessarily be associated with the restoration at all. It could be a result of the insufficient control of patient caries activity (11).

The visual or visual-tactile examinations, often combined with bitewing radiographs, are the most common methods for detecting secondary caries lesions (12, 13). Nevertheless, there is no standard to be recommended for performing such detection, with dentists using various methods, with greater heterogeneity of subsequent treatment decisions (5). Standardized diagnostic criteria for caries around restoration are important since marginal staining and marginal defects are often mistakenly interpreted as an early stage of caries (14). One of the consequences in clinical practice is the high number of replaced restorations performed, being secondary caries the primary reason for this decision-making (15).

However, the criteria on which replacement are based have limited accuracy leading to false-positive diagnoses and invasive interventions (11). Most studies about secondary caries detection were performed in vitro (5). A recent systematic review included only 23 studies about the detection of caries around restoration, and of that, only two investigated caries detection under clinical conditions (5). Besides, only two in vitro studies assessed primary teeth (16, 17).

Among the available criteria to evaluate restorations, two are highlighted due to the current use in research and clinical practice: the International Dental Federation (FDI) criteria (18) and the Caries Associated with Restorations and Sealants (CARS) criteria (19, 20). The FDI criteria were published in 2007 for the first time and were

considered “standard criteria” to be applied when restorative materials or operative techniques are clinically investigated (18). The criteria evaluate three parameters (esthetic, functional, and biological), totalizing 16 criteria expressed with five scores. On the other hand, the CARS system focuses only on caries and has been integrated into the International Caries Classification and Management System (19) and its more recent update, named CariesCare 4D (20). Using the FDI criteria may lead to a more interventional approach, while the CARS system is probably more conservative when it comes to restoration reintervention. Nevertheless, no study has compared the impact of using the FDI criteria and the CARS system clinically in detecting caries lesions around restorations in primary teeth.

The decision on the best method for detecting secondary caries should evaluate whether patients undergoing such methods would have greater health-related benefits than patients undergoing some other method (21). A diagnostic strategy that leads to overtreatment would not be desirable. It is also expected that the correct diagnosis of secondary caries is in line with the current philosophy of minimal intervention approach (22) and prolonging restoration longevity (5).

2 PROPOSITION

The present research aims to investigate the impact of using the International Dental Federation (FDI) criteria and the Caries Associated with Restorations and Sealants (CARS) system for detecting caries lesions around restorations, mainly in primary teeth. Thus, a randomized clinical trial was designed to reach this objective, testing both methods for the caries detection and treatment decision in restored primary teeth. Three chapters were written considering different studies nested in the main trial (the study protocol of the randomized clinical trial, a cross-sectional study, and a delayed type cross-sectional prospective accuracy study). Furthermore, a fourth chapter was written based on an in vitro study designed to compare the use of both FDI and CARS criteria with a digital technology device in permanent teeth. The specific aims of each study were:

I. To describe the randomized clinical trial protocol, methods, and data analysis proposed before the study's beginning.

II. To evaluate the influence of using both clinical criteria to assess caries lesion around restorations on the decision to replace restorations in primary posterior teeth.

III. To investigate the accuracy of both visual methods for caries lesion detection around restorations in primary teeth in a delayed type cross-sectional prospective accuracy study.

IV. To evaluate the in vitro performance of the 3D intraoral scanner and two visual criteria, the FDI and the CARS criteria, in detecting caries lesions and predict their severity around composite restorations in permanent posterior teeth.

3 CHAPTER I: STUDY PROTOCOL

The effect of two clinical criteria in the assessment of caries lesions around restorations in children (CARDEC-03): study protocol for a diagnostic randomized clinical trial

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Abstract

Introduction: The detection of caries lesions around restoration can be challenging. Therefore, the use of some criteria has been proposed to give more objectivity to the diagnosis process. Two of them are the International Dental Federation (FDI) and the Caries Associated with Restorations and Sealants (CARS) criteria. Both methods have a different approach to caries, and it is not possible to know which one of them is the best to use in clinical practice to assess children's restorations. Thus, the present protocol aims to evaluate the effect of using the FDI and CARS criteria in the assessment of caries lesions around restorations in primary teeth on outcomes related to oral health in children and costs resulting from the assessments.

Methods and analysis: A total of 626 restorations of children from three to 10 years were randomly assessed and are being treated following the FDI criteria (FDI group) or CARS criteria (CARS group). Participants will be followed-up after six, 12, 18, and 24 months. The primary outcome will be the need for a new intervention in the evaluated restorations. This outcome consists of several components, and each of these events will be analyzed separately as secondary outcomes. The changes in children’s oral health-related quality of life and the restorative dental treatments cost will also be analyzed as secondary outcomes. The methods will be compared using the Cox regression model with shared frailty. A significance level of 5% will be adopted for all statistical analyses.

Discussion: This will be the first randomized clinical study carried out regarding the detection of caries lesions around restorations in primary teeth.

Trial registration: The study underwent registration in Clinicaltrials.gov (NCT03520309) on 9 May 2018.

Keywords

Randomized Controlled Trial, Dental Caries, Diagnosis, Permanent Dental Restoration, Dental Restoration Repair, Pediatric Dentistry.

3.1 Introduction

Caries lesions around restoration, also known as secondary caries or recurrent caries, are the main reason for restoration failure [1]. However, the detection of these lesions can be challenging for a few reasons, as the presence of gaps between the restoration and tooth surface [2] and the presence of stained margins on resin-based composite restorations makes it difficult to differentiate between lesions and demineralization [3]. For this reason, the use of some criteria has been proposed to give more objectivity to the diagnosis process.

One such set of criteria is the International Dental Federation (FDI) criteria [4], developed in 2007. Although largely used to assess restorations, it evaluates some aspects that might not be related to caries lesions, such as marginal staining and marginal adaptation. However, these aspects could be relevant to be evaluated when using the FDI criteria since many dentists and studies associate marginal staining and defects in the marginal adaptation with the presence of caries lesion around the restoration [5]. Using these criteria may lead to a more interventional approach. Another set of criteria is the Caries Associated with Restorations and Sealants (CARS) criteria, which has been integrated into the International Caries Classification and Management System [6] and its more recent update, named CariesCare 4D [7]. The CARS criteria [6] focus on aspects related to caries and not on other possible reasons for restoration failure. This method is probably more conservative when it comes to restoration reintervention.

When it comes to the management of restorations in primary dentition, it is not possible to know if a more conservative or invasive approach would bring more benefits to children. Restorations that are repaired seem to be more likely to have an additional treatment compared to restorations that are replaced [8]. On the other hand, replacement often causes the loss of healthy dental structure [9,10], leading to a repeated restorative cycle [11], increasing the professional time and costs for health systems [9].

It would be preferable that the criteria for assessing caries around restorations in children is in line with the philosophy of minimal intervention dentistry [12]. However, the majority of studies about the detection of these lesions were performed in vitro, assessed caries lesion in permanent teeth, and did not evaluate relevant aspects to the clinical practice [5,13]. This lack of evidence inspires the conduction of a third

study, which is part of an initiative that aims to build scientific evidence for diagnostic strategies in children - CARies DEtection in Children nº 3 (CARDEC-03).

Thus, this trial aims to evaluate the effect of the use of two different visual criteria, the FDI and CARS criteria, for assessing caries lesions around restorations in primary teeth on outcomes related to children's oral health and costs resulting from the assessments. We hypothesize that the diagnostic criteria that lead to a more conservative approach would bring more benefits to children's oral health, decreasing the treatment costs and professional time.

3.2 Methods

A controlled, triple-blind (participant, care provider, outcomes assessor), randomized clinical trial with two parallels arms (1:1) is being carried out. The present protocol is reported according to the Standard Protocol Items: Recommendations for Interventional Trials (SPIRIT) guidelines [14]. The completed checklist can be accessed at the Figshare online repository [15]

The local ethics committee from the School of Dentistry of the University of São Paulo, São Paulo, Brazil, previously approved the study (registration no. 2.291.642) on 22 September 2017. The participants of the study were recruited from 16 November 2017 to 30 November 2018. The trial was retrospectively registered on Clinicaltrials.gov (NCT03520309) on 9 May 2018 and the initial release started on 6 March 2018. The explanation for registration deficiencies is due to the lack of knowledge that registration must occur before enrolling the first study participant in the trial. However, no changes were made to the study after approval by the local ethics committee in 2017, and no results were analyzed before the trial registration on Clinicaltrials.gov. The authors are aware of possible causes of publication bias and selective reporting and are committed to promoting complete transparency in our research.

Participants, interventions, and outcomes

Study setting

This trial is being conducted at the School of Dentistry Dental Clinic of the University of São Paulo, Brazil. The participants (three to 10 years old) were selected

from a list of patients who sought dental treatment at the School of Dentistry. Those that fulfilled the eligibility criteria were randomly allocated to the intervention groups. A random sequence was generated using the website “Sealed envelope” through the tool “Create a randomisation list”. The patients were included in the study after their legal guardians signed the informed consent form and literate children signed an assent form. Both documents are available as Extended data in English [16,17] and original language [18,19].

Participant eligibility

The inclusion criteria for the present study are children:

a) Who have sought treatment at the School of Dentistry;

b) From three to 10 years old;

c) Presenting at least one restoration of any restorative material (composite resin, amalgam or glass ionomer cement), regardless of its condition, on a primary tooth (anterior or posterior) without fistula, abscess, pulp exposure, history of spontaneous dental pain or mobility.

The exclusion criteria for the present study are children:

a) Whose parents refuse to participate in the study;

b) Who did not agree to participate or showed behavior problems during the first appointment.

All children’s restorations which fulfill the inclusion criteria were included for the assessment.

Allocation: sequence generation and concealment mechanism

Firstly, participants were stratified into different strata: (1) children aged 3 to 6 years presenting three restorations or less; (2) children aged 7 to 10 years presenting three restorations or less; (3) children aged 3 to 6 years presenting more than three restorations; (4) children aged 7 to 10 years presenting more than three restorations. The number of restorations considered for stratification was those placed in primary and permanent teeth. Then, randomization using blocks of different sizes (2, 4, 6 or 8) was performed within each stratum.

All participants of the study could be classified as having a high caries risk since past caries experience is the most important component for the development of caries lesions [20]. However, stratified randomization was performed considering the children number of restorations to subdivide them in children with higher and lower caries experience. The caries lesion activity was not considered for randomization. On the other hand, the children's age was a parameter for stratification in order to consider the different time of exfoliation of the evaluated teeth. In this way, the number of teeth with different time of exfoliation was balanced between the FDI and CARS criteria.

The random sequence was generated using the website “Sealed envelope” through the tool “Create a randomisation list”. It was done by an external examiner and to guarantee allocation confidentiality, blocks with allocation sequences were kept in opaque sequential envelopes.

Interventions

A preliminary visual inspection was performed to assess all participants’ dental surfaces according to the International Caries Detection and Assessment System (ICDAS) [21] described in the CariesCare 4D to detect and assess the caries lesions stage and activity [7]. The assessment was performed by an examiner (LRAP) who is not participating in the subsequent phases of the study. All the assessments of the study are being conducted under a dental clinic setting using a dental chair and artificial illumination. Participants’ teeth receive a professional oral hygiene using a rotating bristle brush, pumice/water slurry and dental floss. A plane buccal mirror and a ball-point probe are being used for all visual inspection and tactile examination of the clinical trial.

Then, children meeting the inclusion criteria were classified into subgroups for further block stratification, according to the number of restorations present in mouth (0 to 3 restorations vs. more than three restorations) and age (3 to 6 years old vs. 7 to 10 years old).

The children included in the study were randomly allocated in two groups to have their restorations evaluated and treated according to different clinical criteria for caries lesion around restoration:

a) FDI group: diagnosis and treatment decision based on the International Dental Federation (FDI) criteria [4] (Table 1 and Figure 1).

b) CARS group: diagnosis according to the Caries Associated with Restorations and Sealants (CARS) detection criteria, described in the ICCMS [6] and in CariesCare 4D [7] (Table 2 and Figure 2), and proposed treatment decision (Table 3). The definitions and characteristics of activity for primary caries from CariesCare International 4D will also be used in association (Table 4).

A clinical example of the restoration assessment performed with both FDI and CARS criteria is illustrated in Figure 3.

The restorations assessment was performed by an examiner (BLPM), who was trained and calibrated before the beginning of the study. Calibration involves a lecture of clinical criteria and training was carried out using photos of clinical cases. A web-based training and calibration tool was also used for this purpose regarding the CARS detection criteria: ICCMS e-learning. The e-learning from ICCMS is an open access service and the tool “ICDAS Calibration for ICCMS(TM)” was used in this study.

After these procedures, the examiner evaluated restorations in 10 children who did not participate in the clinical trial. The examiner repeated the same evaluation, in the same 10 children, for intra-examiner agreement. A benchmark examiner (TLL) also performed the tests to assess inter-examiner reproducibility twice in the same sample of children. In this way, the exams were compounded, and the weighted kappa scores were re-calculated. The assessment of children included in the study started after the intra-examiner and inter-examiner weighted kappa value reached values greater than 0.75 for both FDI and CARS criteria.

For examinations using the FDI criteria, all tooth surfaces are dried before. When using the CARS criteria, teeth are examined firstly wet and then dried for 5 seconds with a dental 3-in-1 air water syringe.

The first assessment was performed with the participant’s allocated group (FDI or CARS). After reaching the diagnosis and treatment decision according to the allocated group, the same examiner performed a second assessment according to the other criteria. This procedure aims to compare the methods since a cross-sectional study was developed nested in this randomized clinical trial. The second assessment did not influence or change the classification and treatment decision proposed by the criteria the participant is allocated. If a legal guardian presents a

complaint related to any children's restoration, it can be repaired or replaced independently of the criteria used. The scores obtained with the restoration assessment were collected using a specific sheet that can be found as Extended data in English [22] and Portuguese [23].

At the first appointment, legal guardians were asked to answer a questionnaire to assess the impact on children's oral health-related quality of life. The instrument used was the Brazilian version [24,25] of the Early Childhood Oral Health Impact Scale (ECOHIS) [26]. We decided to use an instrument answered by the parents since our sample's age range is large and involves small children who would have difficulty answering other questionnaires. This choice was made to allow data to be collected for the entire sample and for the same instrument to be standardized. Besides that, an anamnesis related to children's health and medical history was carried out (this form is available as Extended data in English [27] and original language [28]). At the end of the first appointment, oral hygiene instructions were delivered, showing the correct use of toothbrush and fluoride toothpaste (1000 to 1500 ppm of fluoride) [29]. Dietary advice was also given to all participants and their parents or legal guardians to reduced intake of free sugars throughout the life course [30].

For all appointments, the time spent, and materials used on patient care are collected using a specific sheet that can be found as Extended data in English [31] and original language [32]. Parents or guardians are asked about transportation and absenteeism in the workplace.

Dental treatment protocols

In the subsequent appointments, dental treatments following a predefined protocol are being performed by postgraduate dental students in Pediatric Dentistry, who are blind to the criteria used to reach the treatment decision. In all situations, if there is active dentine tissue, it is removed using dentin excavators. Diamond burs are used to remove the restorations, if necessary.

The treatment decisions for the restorations evaluated according to the FDI and CARS criteria are being classified into:

- No treatment: no intervention needed, and the restoration will be followed-up;

- Professional topical fluoride application: a treatment for non-cavitated active caries lesions detected by the CARS criteria;
- Refurbishment: restorations finishing and polishing;
- Repair: minimally invasive approach resulting in the addition of a restorative material, with or without a preparation of the restoration and/or dental hard tissues [33]. Composite resin or glass ionomer cement will be used as a restorative material;
- Replacement: complete removal of the restoration present on the tooth [33]. Composite resin will be used as restorative material for the new restoration.

The presence or absence of soft or hard carious tissue is evaluated and recorded by the postgraduate dental student who provides dental care after the restoration removal when replacement is indicated. Training and calibration were conducted before the assessments. An experienced researcher in Cariology performed a theoretical lecture about the clinical characteristics of caries lesions, and training was carried out using photos of clinical cases. The procedure of evaluating the carious tissue is performed to record a possible false-positive diagnosis for dentine caries lesion around the restoration. The authors will also develop an accuracy study nested in this clinical trial.

The same operators are performing additional dental treatment needs (not related to the restorations included in the study). Treatment plan related to additional dental treatment was carried out by the examiner responsible for children's initial clinical examination. Details of the pre-established treatment protocols can be found in Figure 4.

Follow-up visits

After the completion of the treatment plan, participants will be followed up considering the outcome evaluation after six, 12, 18, and 24 months. At the follow-up visits, if a new dental treatment is needed (related or not to the restorations), necessary procedures will be carried out. Hygiene and dietary instructions will be given to children at each follow-up visit.

The treatment decisions for the restorations evaluated during the follow-up visits will be decided according to the FDI or CARS criteria, considering the child’s allocation group. The same trained and calibrated examiner (BLPM) who conducted

the assessments at the beginning of the study, with the FDI or CARS criteria, will perform the assessments with the FDI or CARS criteria during all follow-up visits.

During the 24 months follow-up visit, a new ECOHIS questionnaire will be applied for parents or legal guardians who had previously answered at the time the child was included in the study.

Adherence

The stimulus to the participants' adherence to the treatment and follow-up sessions are happening through contacts via mobile and social networks. Facebook and an Instagram profile were created to stay in touch with the patient through social media. Humanized care is provided for all participants, focusing on the patient's well-being and providing empathy, affection, and familiarity between the CARDEC collaborative group and children and their families. Explanations about the importance of participation for their benefit are also being given.

Outcomes

The primary outcome of this trial will be the need for a new intervention during the follow-up of restorations evaluated by different criteria. This outcome consists of several components. Thus, the outcome occurrence will be considered if any of the following conditions are detected:

- Presence of secondary caries lesion exposing dentin;
- Need for repair;
- Need for restoration replacement;
- Need for extension of the existing restoration on the examined tooth due to a tooth fracture or caries lesion development exposing dentin;
- An episode of pain or need for endodontic treatment;
- Extraction requirement (except in the case of prolonged retention).

The occurrence of any of these conditions at any time of follow-up will be considered as an event related to the primary outcome. Each of the events that make up the primary outcome will be analyzed separately as secondary outcomes. Changes in children's oral health-related quality of life after two years will be considered as a secondary outcome. The costs and effects per child of the

treatments performed during the follow-up, considering the teeth included in our sample, are also going to be analyzed as a secondary outcome.

The occurrence of the outcomes will be evaluated according to predetermined criteria from two other criteria during the follow-up visits of six, 12, 18, and 24 months. Different criteria will be used according to the number of surfaces the restoration involves:

- For one-surface restorations: the criteria used will be according to Frencken et al. [34];
- For a multi-surface restoration: the criteria used will be according to Roeleveld et al. [35].

According to Frencken et al. [34] criteria, scores related to restoration success will be 0, 1 or 7. Those considered to have failed will be scored as 2, 3, 4 or 8; while those considered being unrelated to success and failure will be scored as 5, 6 or 9. Concerning the Roeleveld et al. [35] criteria, restoration success will be scored as 00 or 10. Those considered to have failed will be scored as 11, 12, 13, 20, 21, 30 or 40; while those considered being unrelated to success and failure will be scored as 50, 60, 70 or 90.

The information regarding presence of secondary caries lesions exposing dentin; the need for repair; the need for restoration replacement; the need for extension of the existing restoration on the examined tooth; the need for endodontic treatment, and extraction requirement are obtained directly using the criteria systems proposed (Frencken et al. [34] and Roeleveld et al. [35]). In cases of suspected pulp involvement, a radiograph is taken. We also asked the parents about pain occurrence.

The follow-up evaluations will be carried out by an examiner (TKT) blind to the children’s allocation group. The examiner was previously trained and calibrated for both criteria (the weighted Kappa value for interexaminer was 0.89, and the intra-examiner agreement was 0.94). The researcher (TKT) did not participate in the previous phases of the trial and will perform the evaluations according to the Frencken et al. [34] or Roeleveld et al. [35] during all follow-up visits (six, 12, 18, and 24 months), considering the number of restorations surface, to assess the outcome of the study.

Sample size

The sample size calculation was performed based on the primary outcome (percentage of restorations requiring reintervention). A failure rate of 10% after two years was considered for occlusal restorations [36] and 30% for occlusal-proximal restorations [37]. It was also considered that approximately 10% of the replaced restorations and 14% of the restorations undergoing repair fail again [8]. Considering that half of the sample is occlusal restorations, an operative reintervention requirement rate of 24% is expected in two years. The minimum number of 522 restorations was reached, based on an absolute difference of 10% between the groups, using a two-tailed test. As a child can contribute with more than one restoration, 20% was added to the sample size (n = 626).

Considering that children with restored teeth have on average 3.7 restorations [38], and adding 20% for possible participants loss, a minimum number of 204 children presenting at least one restored primary tooth (without fistula, abscess, pulp exposure, history of spontaneous dental pain or mobility) is required to be included in this trial.

Data management and analysis

Data management

Clinical data will be entered directly into predetermined sheets. Data quality will be ensured by validation checks that include missing data, out-of-range values, and illogical and invalid responses.

Statistical methods

Examiners' reproducibility will be performed using the weighted kappa test, calculating the weighted value of kappa and also the 95% confidence intervals. The primary outcome of the study is a dichotomous variable (with or without the need for intervention); therefore, the unit of analysis is the restored tooth. As children can have more than one tooth included in the study, the comparison between the groups will be carried out using survival analysis, considering the cluster-effect. Kaplan-

Meyer graphs will be constructed, and the methods will be compared using the Cox regression model with a shared frailty.

Secondary clinical outcomes will also be analyzed using the same statistical tests. Quality of life will be analyzed using Poisson regression analysis and the unit of analysis will be the child.

A trial-based economic evaluation will be performed considering the difference of the inputs (costs) and outputs (effects) of the two diagnostic criteria (FDI and CARS) after two years. Further details regarding the economic evaluation will be described on a health economic analysis plan.

A p-value of 5% as the level of significance will be considered for all tests. The analyses will be performed using the statistical package Stata 13.0 (Stata Corp, College Station, USA).

Participant recruitment and timeline

Recruitment took place at the School of Dentistry of the University of São Paulo from November 2017 to November 2018. Each allocated participant will have an average treatment period of one month and will be followed-up for 24 months, resulting in a total of 25 months of enrollment. The detailed timeline for data collection is summarized in Figure 5.

Monitoring

Data monitoring

No data monitoring committee is needed in this trial since adverse events are unlikely to happen during restoration evaluation and dental treatments. For this reason, the chief investigator of the study (FMM) will assume an independent oversight of trial data collection, management, and analysis.

Harms

The effects expected in this study are the ones listed as trial outcomes. All of them are usually expected to happen during pediatric dentistry clinical practice. Any other adverse event is unlikely to happen.

Auditing

The data will be periodically subjected to audit by the coordinator of the study. Any discrepancies will be verified, corrected and registered.

Ethics and dissemination

Confidentiality

Sequential numbers will be used to identify and ensure participant confidentiality. Participants' identifiable information will be stored in filing cabinets in a locked secure room.

Access to data

The full data generated from this trial will be placed in a public repository (University of São Paulo Data Repository).

Ancillary and post-trial care

Participants included in this trial will have dental treatments provided at the School's dental clinic during and after the completion of the trial if necessary.

Dissemination policy

All the findings of this trial will be reported in peer-reviewed journals, patient newsletters and a website (School of Dentistry of University of São Paulo website).

Study status

The patient recruitment took place from 16 November 2017 to 30 November 2018. The follow-up evaluations of 6 and 12 months were concluded; however, the study is now temporarily suspended since 16 March 2020 due to COVID-19.

3.3 Discussion

Restoration assessment is a challenge in dentistry, and the main point of debate is caries around restoration [1,39]. However, due to the scarcity of well-conducted studies, its diagnosis is not based on objective clinical criteria, and there is a considerable variation in the criteria used. As a consequence, a significant number of

restorations presenting small defects are often indicated to be replaced since they can be misdiagnosed as caries lesions [9]. Also, there is no homogeneity on the treatment decision-making for secondary caries between dentists [5,40], and studies based on clinical practice have shown that they tend to replace more restorations than necessary [41].

Two recently published systematic reviews included around 20 accuracy studies of methods for detecting caries lesions around restorations [5,13]. The majority of these studies were performed in vitro, assessed caries lesions in permanent teeth, and did not evaluate relevant aspects to the clinical practice [5,13]. Nevertheless, the decision on what is the best method to be used should evaluate whether patients undergoing such methods would have greater health-related benefits than patients undergoing some other method [42]. For this assessment, ultimate health outcomes for patients must be considered. The experimental design to assess it is the randomized clinical trial (Phase IV question).

Randomized clinical trials are considered the best study design on which clinicians and policymakers rely most to determine whether an intervention is effective [43]. However, as far as we know, no randomized clinical study has been carried out regarding the detection of caries lesions around restorations in primary teeth. Besides that, no study compared the accuracy of FDI and CARS criteria clinically to detect caries around restoration on primary teeth, and the impact of the use of the criteria on the restorative treatment decisions for children. For this reason, an accuracy study (Phase III question) with the FDI and CARS methods will be developed nested to this trial.

For the present trial, the authors decided to use among the FDI criteria the subcategories marginal staining and marginal adaptation, beyond recurrence of caries. The decision was based on the fact that both aspects can be misinterpreted with secondary caries during restoration assessment [44–46]. Therefore, we tried to simulate what can clinically be a reason for restoration reintervention in the daily clinical practice. Regarding the CARS criteria, the system does not present any treatment decision linked to the evaluation method. For this reason, we adapted the decisions based on the ICCMS recommendations for treating primary caries lesions [6].

The criteria systems used to assess the study outcome, although different, were defined mainly to evaluate our primary endpoint, which is the necessity of

replacement of the restoration. The difference between the two criteria is because one is used to assessing one-surface restorations (Frencken et al. [34]), and the other is used for assessing multi-surface restoration (Roeleveld et al. [35]). However, both are used to evaluate the necessity of restoration replacement. Regarding the patient perspective, the reason that led to the replacement probably is not important. We could assess this information with some patient-reported variables (or proxies, reported by the parents). The suitability of the two criteria for the dentists will not be evaluated in our study. Still, we can speculate about this topic in the main manuscript after obtaining the results.

The study's limitation is that the first assessment performed with the participant's allocation group (FDI or CARS criteria) and the second assessment according to the other criteria will be done at the same dental appointment. This will be done to reduce the number of dental appointments for the patients, enhancing their adherence to the clinical research. However, a carry-over effect could occur between the methods. Contrariwise, a strength of the study is the procedure used to avoid selection bias. The evaluations will be conducted in a sample of children randomly selected from a list of patients who sought dental treatment at our School. Besides that, the outcome assessor will be blinded regarding the allocation group to avoid assessment bias.

Thus, with the development of this clinical trial and expected results, we aim to define between FDI and CARS criteria the best approach for diagnosis and management of dental restorations in children, considering the impact on the treatment decision on clinically relevant outcomes for the patient and costs resulting from the treatments performed.

Data availability

Underlying data

No data are associated with this article.

Extended data

Figshare: Consent form. https://doi.org/10.6084/m9.figshare.12327644.v1 [16].

Figshare: Consent form in the original language (Portuguese). https://doi.org/10.6084/m9.figshare.12327674.v1 [18].

Figshare: Assent form. https://doi.org/10.6084/m9.figshare.12327731.v1 [17].
Figshare: Assent form in the original language (Portuguese).
https://doi.org/10.6084/m9.figshare.12327779.v1 [19].
Figshare: Restorations assessment form.
https://doi.org/10.6084/m9.figshare.12331460.v1 [22].
Figshare: Restorations assessment form in the original language (Portuguese).
https://doi.org/10.6084/m9.figshare.12331466.v1 [23].
Figshare: Anamnesis form. https://doi.org/10.6084/m9.figshare.12324212.v1 [27].
Figshare: Anamnesis form in the original language (Portuguese).
https://doi.org/10.6084/m9.figshare.12327578.v1 [28].
Figshare: Time and cost form. https://doi.org/10.6084/m9.figshare.12327854.v1 [31].
Figshare: Time and cost form in the original language (Portuguese).
https://doi.org/10.6084/m9.figshare.12331451.v1 [32].

Reporting guidelines
Figshare: SPIRIT checklist. https://doi.org/10.6084/m9.figshare.12331484.v1 [15].

Competing interests

No competing interests were disclosed.

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Tables

Table 1 - International Dental Federation (FDI) criteria linked to the treatment decision - adapted

FDI scores					FDI treatment
Scores	**Classification**	**Marginal staining***	**Marginal adaptation**	**Recurrence of caries**	**Indication**
1	**Clinically excellent/ very good**	No marginal staining	Harmonious outline, no gaps, no white or discolored lines	No secondary or primary caries	No treatment
2	**Clinically good**	Minor marginal staining, easily removable by polishing	Marginal gap (<150 µm), white lines. Small marginal fracture removable by polishing. Slight ditching, slight step/flashes, minor irregularities. Gap < 250µm not removable	Very small and localized demineralization	No treatment
3	**Clinically sufficient/ satisfactory**	Moderate marginal staining, not esthetically unacceptable	Several small marginal fractures. Major irregularities, ditching or flash, steps. Gap > 250µm or dentine/base exposed	Larger areas of demineralization	No treatment
4	**Clinically unsatisfactory**	Pronounced marginal staining; major intervention necessary for improvement	Severe ditching or marginal fractures. Larger irregularities or steps	Caries with cavitation	Repair
5	**Clinically poor**	Deep marginal staining, not accessible for intervention	Restoration (complete or partial) is loose but in situ. Generalized major gaps or irregularities	Deep secondary caries or exposed dentine that is not accessible for repair of restoration	Replacement

Source: The author

Table 2 - Caries Associated with Restorations and Sealants (CARS) criteria - adapted

Caries Associated with Restorations and Sealants codes		
Code 0	**Sound tooth surface with restoration or sealant**	A sound tooth surface adjacent to a restoration/sealant margin. There should be no evidence of caries (either no or questionable change in enamel translucency after prolonged air drying for 5 seconds). Surfaces with marginal defects less than 0.5mm in width (i.e. will not admit the ball end of the CPI Probe), developmental defects such as enamel hypoplasias; fluorosis; tooth wear (attrition, abrasion and erosion), and extrinsic or intrinsic stains will be recorded as sound. Stained margins consistent with non-carious habits (e.g. frequent tea drinking) and which do not exhibit signs consistent with demineralization should be scored as sound.
Code 1	**First visual change in enamel**	When seen wet there is no evidence of any change in color attributable to carious activity, but after prolonged air drying (for approximately 5 seconds) an opacity or discoloration consistent with demineralization is visible that is not consistent with the clinical appearance of sound enamel.
Code 2	**Distinct visual change in enamel/dentin adjacent to a restoration margin**	If the restoration margin is placed on enamel the tooth must be viewed wet. When wet there is an opacity consistent with demineralization or discoloration that is not consistent with the clinical appearance of sound enamel (Note: the lesion is still visible when dry). If the restoration margin is placed on dentin: Code 2 applies to discoloration that is not consistent with the clinical appearance of sound dentin or cementum.
Code 3	**Carious defects of <0.5 mm with the signs of code 2**	Cavitation at the margin of the restoration/sealant less than 0.5mm, in addition to either an opacity or discoloration consistent with demineralization that is not consistent with the clinical appearance of sound enamel or with a shadow of discolored dentin.
Code 4	**Marginal caries in enamel/dentin /cementum adjacent to restoration with underlying dark shadow from dentin**	The tooth surface may have characteristics of code 2 and has a shadow of discolored dentin which is visible through an apparently intact enamel surface or with localized breakdown in enamel but no visible dentin. This appearance is often seen more easily when the tooth is wet and is a darkening and intrinsic shadow which may be grey, blue, orange, or brown in color. Note: view tooth wet and then dry. This lesion should be distinguished from amalgam shadows.
Code 5	**Distinct cavity adjacent to restoration**	Distinct cavity adjacent to restoration/sealant with visible dentin in the interfacial space with signs of caries as described in code 4, in addition to a gap > 0.5mm in width. OR In those instances where margins are not visible, there is evidence of discontinuity at the margin of the restoration/sealant and tooth substance of the dentin as detected by 0.5mm ball-ended probe run along the restoration/sealant margin.
Code 6	**Extensive distinct cavity with visible dentin**	Obvious loss of tooth structure, the extensive cavity may be deep or wide and dentin is clearly visible on both the walls and at the base.

Source: The author

Table 3 - Treatment decision linked to the Caries Associated with Restoration and Sealants (CARS) criteria – adapted

CARS code	CARS Treatment		
0	**No treatment**	No treatment	**-**
1	**Non-operative treatment**	No treatment [1] Topical fluoride application [2]	[1] Adjacent inactive lesion [2] Adjacent active lesion
2		No treatment [1] Topical fluoride application [2]	
3		No treatment [1] Topical fluoride application [2]	
4	**Operative treatment**	Repair Replacement[3]	[3] Replacement should be indicated in case the carious lesion involves more than half of the restoration.
5		Repair Replacement[3]	
6		Repair Replacement[3]	

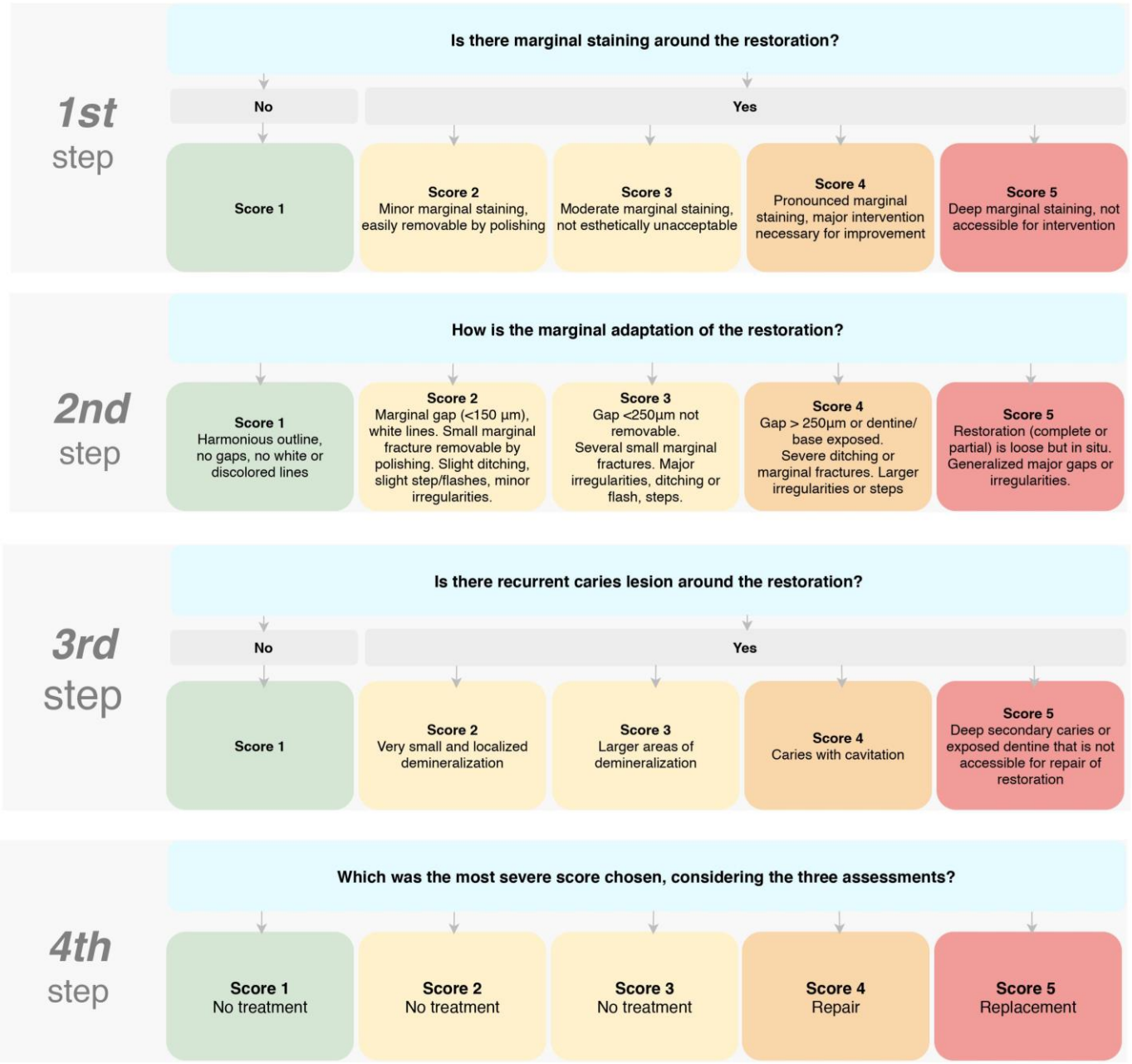
Source: The author

Table 4 - Characteristics of active and inactive caries linked to caries around restorations system - Caries Associated with Restoration and Sealants (CARS) – adapted

ICCMS Code	Characteristics of Lesion	
	Signs of Active Lesions	Signs of Inactive Lesions
ICCMS Initial and Moderate Caries Stage	Surface of enamel is whitish/yellowish; opaque with loss of luster, feels rough when the tip of the ball-ended probe is moved gently across the surface. Lesion is in a plaque stagnation area, i.e. in the entrance of pits and fissures, near the gingival margin or, for proximal surfaces, below or above the contact point. The lesion may be covered by thick plaque prior to cleaning	Surface of enamel is whitish, brownish or black. Enamel may be shiny and feels hard and smooth when the tip of the ball-ended probe is moved gently across the surface. For smooth surfaces, the caries lesion is typically located at some distance from the gingival margin. Lesion may not be covered by thick plaque prior to cleaning
ICCMS Extensive Caries Stage	Dentine feels soft or leathery on gentle probing	Dentine is shiny and hard on gentle probing

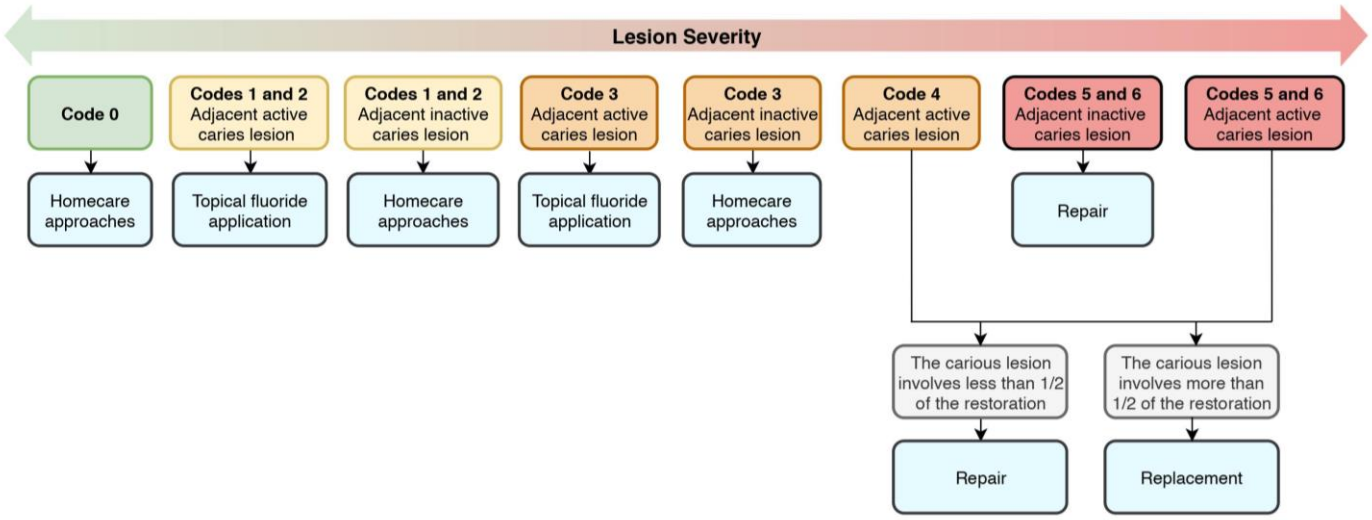
Source: The author

Figure 1 - Patient's plan decision flowchart based on the International Dental Federation (FDI) criteria



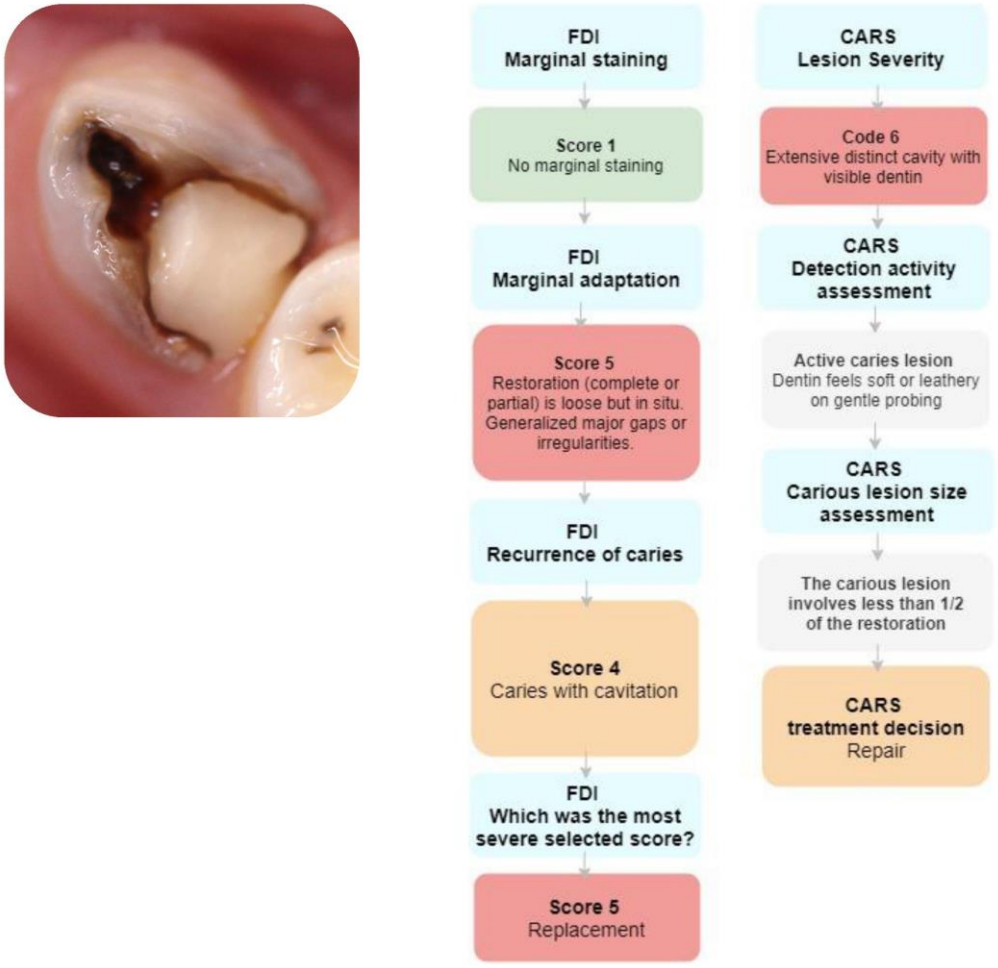
Source: The author

Figure 2 - Patient's plan decision flowchart based on the Caries Associated with Restoration and Sealants (CARS) criteria



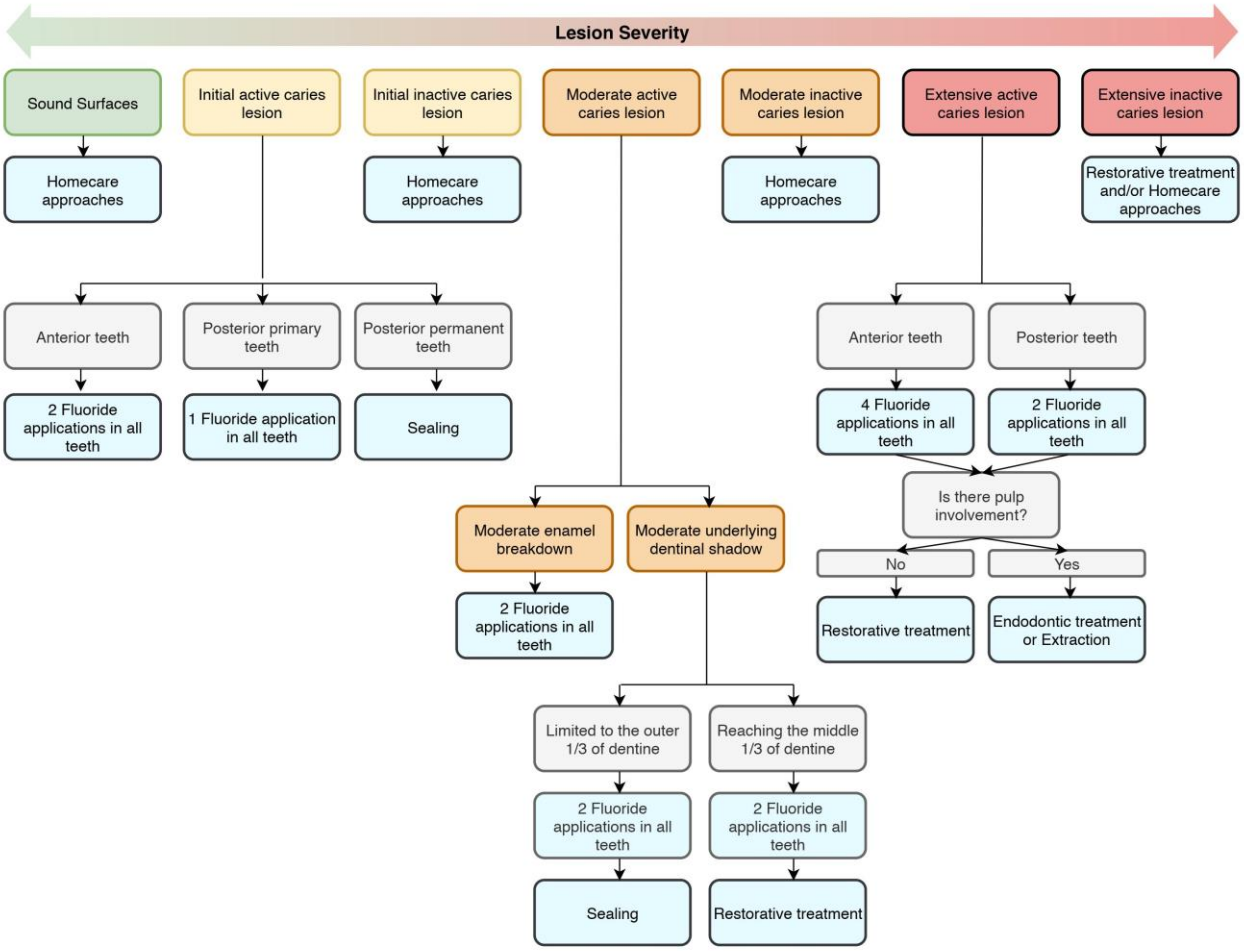
Source: The author

Figure 3 - Clinical example of the restoration assessment performed in a primary posterior tooth according to the FDI and CARS criteria



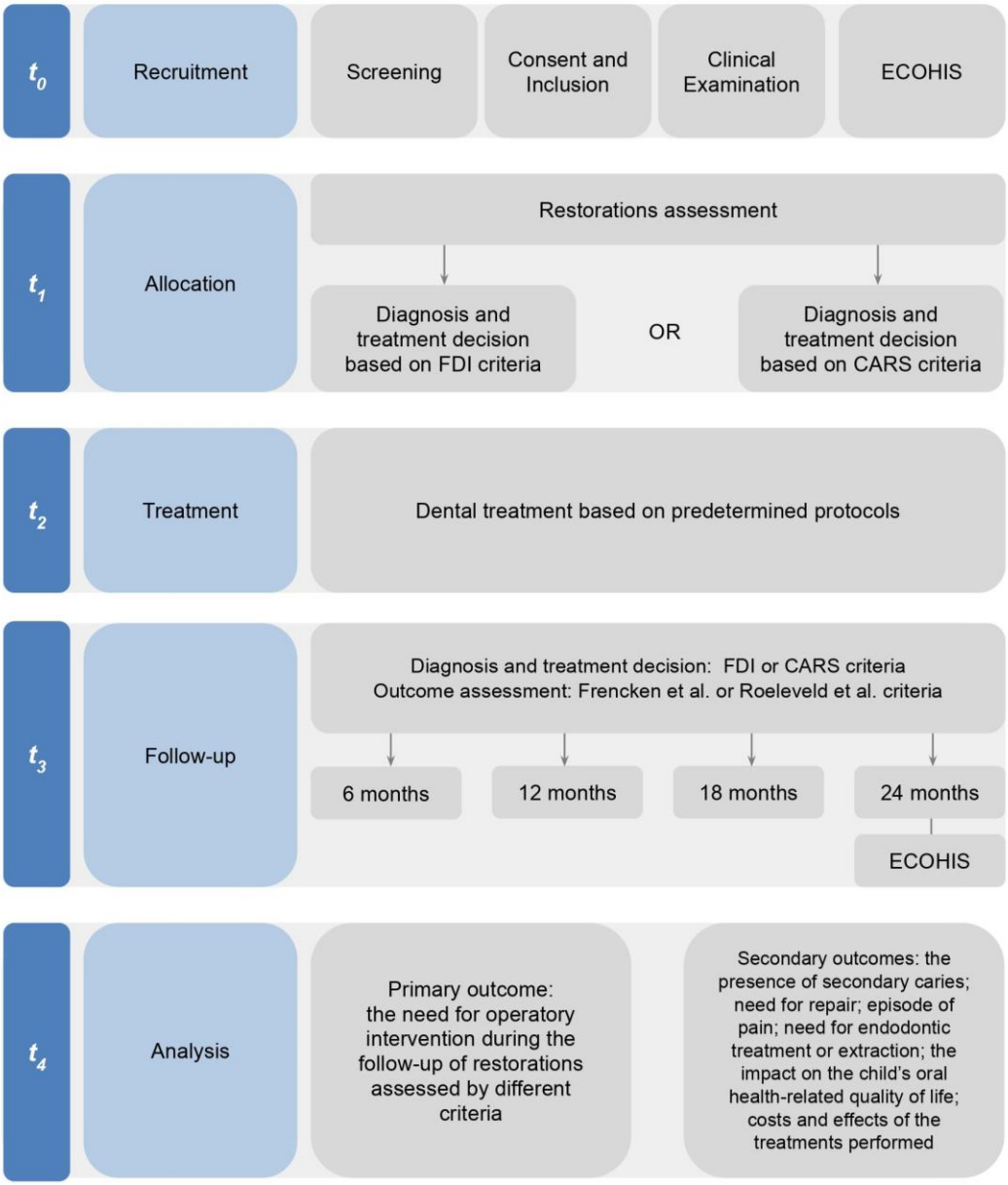
Source: The author

Figure 4 - Patient's plan decision flowchart based on the International Caries Detection and Assessment System (ICDAS) criteria



Source: The author

Figure 5 - Clinical trial's timeline



Source: The author

Extended data - Consent form

Participant Consent Form

Your child is being invited to participate voluntarily in the research entitled **THE IMPACT OF THE USE OF DIFFERENT CLINICAL CRITERIA FOR THE ASSESSMENT OF CARIES LESIONS AROUND RESTORATIONS IN PRIMARY TEETH: RANDOMIZED CLINICAL TRIAL**. Professor Fausto Medeiros Mendes is the principal investigator of the trial. The following researchers are going to participate in the study Mariana Minatel Braga, Daniela Prócida Raggio, José Carlos Pettorossi Imparato, Maximiliano Sérgio Cenci, Elenara Ferreira de Oliveira, Kim Rud Ekstrand, Tathiane Fernandes de Novaes, Tamara Kerber Tedesco, Thais Gimenez, Bruna Lorena Pereira Moro, Laura Regina Antunes Pontes, Renata Pereira de Samuel Marques, Nathalia de Miranda Ladewig, Isabel Cristina Olegário da Costa, Ana Laura Pássaro, Cintia Saori Saihara, and Cácia Signori. It will be conducted at the School of Dentistry at the University of São Paulo. This document will also provide more information on the procedures to be performed, which will be detailed below. Participation is not mandatory, and there will be no loss if you refuse your child to participate.

This research aims to evaluate restorations in primary teeth (milk teeth) and compare two different visual criteria to detect caries lesions around restorations. Some studies have already demonstrated that new restorations often replace restorations with small defects such as stains. We believe this practice can be considered an unnecessary dental treatment, and it might weaken the tooth. For this reason, we want to find a diagnostic method that guarantees greater longevity for restorations and oral health for children.

All children will undergo an initial caries lesion assessment. A plane buccal mirror and a ball-point probe (an instrument with a small ball at the end) will be used. The child will then be drawn to one group according to two diagnostic criteria for restoration assessment. The dentist who performs this evaluation will clean the child's teeth with a rotating bristle brush, pumice/water slurry, and dental floss. A plane buccal mirror and a ball-point probe will be used again to assess the restorations and the presence of caries around them. After the evaluation, the same dentist will decide if there will be no treatment for the evaluated restoration, if it will be repaired, or if a new restoration will replace it.

A second restoration assessment will be performed according to the other criteria that were not selected. This evaluation will only be used for future comparison of the data and will not influence the classification and treatment proposed by the method carried out the first time. Only the dentist who makes the diagnosis will know in which group the child was allocated. Neither the legal guardians, the child, and the dentist who will treat the child will be aware of the group.

Research participant's signature	Trial coordinator signature

Source: The author

The treatments will be carried out by other dentists according to predefined protocols. These dentists will also plan and perform the dental treatment of the child, if necessary. After finishing the restorations treatments, children will be reexamined after 6, 12, 18, and 24 months. However, if there are any problems between these reevaluations, you need to communicate with the researchers. If there is any need for treatment during this period, the child will be cared for and treated. After these 24 months, children will continue to be assisted by the Pediatric Dentistry Discipline for any complications resulting from the research. If a severe problem is identified with one of the criteria for evaluating restorations, the study can be interrupted, and the child will be attended.

The risks expected for this research are minimal, being the same as children would be exposed to during standard pediatric dental care. The difference between the study groups is the criteria used to evaluate the restorations. However, the two strategies used are described in the literature and are used by dentists. The objective of the study is to know which approach brings more benefits to patients.

The child who participates in the research will benefit from the diagnosis and treatment of all oral health problems. The results of this research may contribute to all children in the future to receive the best diagnosis strategy of restorations and, consequently, better planning of their dental treatment.

The child's legal guardian may choose not to participate in the research. He/She may have the possibility to withdraw his consent and stop participating in the study at any time without any penalty on the part of the trial coordinator. The child dental treatment will be guaranteed, even if you stop participating in the research or if the study is interrupted.

The participant and his companion will have reimbursement for all expenses resulting from participating in this research. Besides, in case of damages resulting from the study, the research participant will receive full and immediate assistance, free of charge for as long as necessary.

The identity of participants and their legal guardians will not be disclosed, even in the dissemination of the results. The researchers guarantee the confidentiality of the information and are committed to using the data collected only for this study. At the end of the trial, participants will be informed about the results. The data obtained will be published, regardless of whether they are favorable or not.

If there is any problem or doubt during the research, the trial coordinator can be reached by calling (11) 9 9153-9355 or (11) 3091-7835, extension 208, to speak with Fausto Medeiros Mendes.

Research participant's signature	Trial coordinator signature

Source: The author

If there are concerns regarding the ethical aspects of the research, contact CEP-FOUSP - Research Ethics Committee of the School of Dentistry at the University of São Paulo - Avenida Professor Lineu Prestes nº 2227 - 05508-000 - São Paulo - SP – Telephone number + 55 (11) 3091.7960 - e-mail cepfo@usp.br. The opening hours to the public and researchers are: Monday to Friday from 9 am to 12 pm and from 2 pm to 4 pm (except on holidays and university recess). The Committee is an interdisciplinary and independent collegiate body of public relevance of a consultative, deliberative and educational nature. It was created to defend the interests of research participants in their integrity and dignity to contribute to the development of research within ethical standards. (CNS Resolution No. 466 of 2012).

I declare that I have been sufficiently informed about the information that I read or that was read to me, describing the research entitled **"THE IMPACT OF THE USE OF DIFFERENT CLINICAL CRITERIA FOR THE ASSESSMENT OF CARIES LESIONS AROUND RESTORATIONS IN PRIMARY TEETH: RANDOMIZED CLINICAL TRIAL"**. I voluntarily agree to participate in the study. I will be able to withdraw my consent at any time without penalty or loss of any benefit that I may have acquired in this service.

This document was prepared in two copies, one for the research participant and the trial coordinator.

Name of the research participant: _____

Legal guardian's name: _____

Legal guardian's signature: _____

Date:_____/_____/_____

I declare that I have obtained the Participant Consent Form from this patient or legal guardian in an appropriate and volunteer way to participate in this research.

Nome of the trial coordinator: Fausto Medeiros Mendes

Signature: _____

Date:_____/_____/_____

Source: The author

Extended data - Consent form in the original language (Portuguese)

Termo de Consentimento Livre e Esclarecido

Por esse documento, o Sr(a) está sendo convidado para que seu (sua) filho (a) participe voluntariamente da pesquisa intitulada **IMPACTO DO USO DE DIFERENTES CRITÉRIOS CLÍNICOS NA AVALIAÇÃO DE LESÕES DE CÁRIE AO REDOR DE RESTAURAÇÕES EM DENTES DECÍDUOS: ESTUDO CLÍNICO RANDOMIZADO** tendo como Pesquisador Responsável o Prof. Dr. Fausto Medeiros Mendes, com a participação dos pesquisadores Mariana Minatel Braga, Daniela Prócida Raggio, José Carlos Pettorossi Imparato, Maximiliano Sérgio Cenci, Elenara Ferreira de Oliveira, Kim Rud Ekstrand, Tathiane Fernandes de Novaes, Tamara Kerber Tedesco, Thais Gimenez, Bruna Lorena Pereira Moro, Laura Regina Antunes Pontes, Renata Pereira de Samuel Marques, Nathalia de Miranda Ladewig, Isabel Cristina Olegário da Costa, Ana Laura Pássaro, Cintia Saori Saihara e Cácia Signori, na Faculdade de Odontologia da Universidade de São Paulo. Este documento também dará maiores informações sobre os procedimentos a serem realizados, que serão detalhados a seguir. Sua participação não é obrigatória e não haverá prejuízo algum, caso se recuse a participar.

O objetivo desta pesquisa é avaliar a qualidade das restaurações em dentes decíduos (de leite) e comparar dois diferentes critérios visuais para detecção de lesões de cárie ao redor de restaurações. Alguns estudos já realizados mostram que restaurações com pequenos defeitos como manchamentos, por exemplo, são muitas vezes substituídas por novas restaurações. Nós acreditamos que isso pode ser considerado um tratamento desnecessário, capaz de enfraquecer o dente. Por isso nós queremos encontrar um método de diagnóstico capaz de garantir maior longevidade para as restaurações, assim como saúde bucal para as crianças.

Todas as crianças passarão por uma avaliação inicial para verificar a presença de lesões de cárie, na qual serão utilizados um espelho e uma sonda OMS (um instrumento com uma bolinha na ponta). A seguir, será sorteado um grupo para essa criança, de acordo com dois diferentes critérios de diagnóstico para avaliação das restaurações presentes em sua cavidade bucal. A dentista que realizar essa avaliação irá limpar os dentes da criança com auxílio de um micromotor de baixa-rotação, taça de borracha e escova de Robinson com pasta profilática, água e fio dental. Serão utilizados novamente, um espelho e uma sonda OMS para avaliar a qualidade das restaurações e a presença de cárie ao redor das mesmas. Após a avaliação, esta mesma dentista irá decidir se nenhum tratamento será necessário para a restauração avaliada, se será feito um reparo na mesma ou se essa será substituída por uma nova restauração.

As restaurações serão, então, avaliadas pela segunda vez de acordo com o outro critério que não foi o sorteado. Essa avaliação servirá apenas para futura comparação dos dados e não irá influenciar na classificação e no tratamento proposto pelo critério realizado da primeira vez. Apenas o dentista que fará o diagnóstico saberá o grupo em que a criança está, nem os responsáveis, nem a criança e nem o dentista que tratará a criança saberão.

Rubrica do Participante da Pesquisa | **Rubrica do Pesquisador Responsável**

Source: The author

Os tratamentos serão realizados de acordo com protocolos predefinidos e por outros dentistas, que também irão planejar e realizar o tratamento dos outros dentes da criança, caso haja necessidade. Após o término dos tratamentos das restaurações, as crianças serão reexaminadas após 6, 12, 18 e 24 meses. Entretanto, qualquer problema entre essas reavaliações podem e devem ser comunicados aos pesquisadores. Havendo qualquer necessidade de tratamento durante esse período, a criança será atendida e tratada. Após esses 24 meses, as crianças continuarão assistidas pela Disciplina de Odontopediatria para qualquer intercorrência decorrente da pesquisa. Caso seja identificado um problema grave com um dos critérios de avaliação das restaurações, a pesquisa pode ser interrompida e melhor tratamento será garantido à criança.

Os riscos esperados para esta pesquisa são mínimos, sendo os mesmos aos quais as crianças estariam expostas durante um atendimento Odontopediátrico padrão, fora da pesquisa. A diferença entre os grupos do estudo são os critérios utilizados para avaliação das restaurações, porém as duas estratégias utilizadas são descritas na literatura e utilizadas pelos cirurgiões-dentistas, sendo que o objetivo do estudo é saber qual das estratégias traz mais benefícios para os pacientes.

A criança que participar da pesquisa terá como benefício direto o diagnóstico e tratamento gratuito de todos os problemas bucais que ela apresentar. Além disso, os resultados dessa pesquisa poderão contribuir para que todas as crianças futuramente recebam a melhor forma de diagnóstico e avaliação de restaurações e, consequentemente, melhor planejamento do seu tratamento odontológico.

O responsável pelo participante da pesquisa poderá escolher não participar da pesquisa, tendo a possibilidade de retirar seu consentimento e deixar de participar da mesma a qualquer momento sem qualquer penalização por parte do Pesquisador Responsável. O tratamento integral da criança será garantido, mesmo com a interrupção da sua participação na pesquisa por sua própria vontade ou caso o estudo seja interrompido.

O participante e seu acompanhante terão ressarcimento de todos os gastos decorrentes com a participação nesta pesquisa. Além disso, o participante da pesquisa receberá assistência integral e imediata, de forma gratuita pelo tempo que for necessário em caso de danos decorrentes da pesquisa.

Não será revelada, sob nenhuma hipótese, a identidade do participante bem como de seu responsável, mesmo na divulgação dos resultados. Os pesquisadores garantem o caráter confidencial das informações e o participante da pesquisa recebe o compromisso do pesquisador responsável de utilizar os dados coletados somente para esta pesquisa. Ao final da pesquisa, os participantes receberão os resultados encontrados. Os resultados obtidos serão publicados, independentemente de serem favoráveis ou não.

Havendo qualquer problema ou dúvida durante a realização da pesquisa, o pesquisador responsável pode ser encontrado pelos telefones (11) 9 9153-9355 ou (11) 3091-7835, ramal 208, para falar com Fausto Medeiros Mendes.

Rubrica do Participante da Pesquisa	Rubrica do Pesquisador Responsável

Source: The author

Se houver dúvidas em relação aos aspectos éticos da pesquisa, contatar o CEP-FOUSP - Comitê de Ética em Pesquisa da Faculdade de Odontologia da Universidade de São Paulo – Avenida Professor Lineu Prestes nº 2227 – 05508-000 – São Paulo – SP – Telefone (11) 3091.7960 – e-mail cepfo@usp.br. O horário de atendimento ao público e pesquisadores é: de segunda a sexta-feira das 9 às 12h e de 14 às 16h (exceto em feriados e recesso universitário). O Comitê é um colegiado interdisciplinar e independente, de relevância pública, de caráter consultivo, deliberativo e educativo, criado para defender os interesses dos participantes da pesquisa em sua integridade e dignidade para contribuir no desenvolvimento da pesquisa dentro de padrões éticos. (Resolução CNS nº 466 de 2012).

Declaro ter sido suficientemente informado a respeito das informações que li ou que foram lidas para mim, descrevendo a pesquisa **"IMPACTO DO USO DE DIFERENTES CRITÉRIOS CLÍNICOS NA AVALIAÇÃO DE LESÕES DE CÁRIE AO REDOR DE RESTAURAÇÕES EM DENTES DECÍDUOS: ESTUDO CLÍNICO RANDOMIZADO"**. Concordo voluntariamente em participar do estudo e poderei retirar o meu consentimento a qualquer momento, sem penalidade ou prejuízo ou perda de qualquer benefício que eu possa ter adquirido neste serviço.

Este documento foi elaborado em duas vias sendo uma do participante da pesquisa e outra do pesquisador responsável.

Nome do participante da Pesquisa: _____

Nome do responsável legal: _____

Assinatura do responsável legal: _____

Data:_____/_____/_____

Declaro que obtive de forma apropriada e voluntária o Consentimento Livre e Esclarecido deste paciente ou representante legal para a participação nesta pesquisa.

Nome do Pesquisador Responsável: Fausto Medeiros Mendes

Assinatura: _____

Data:_____/_____/_____

Source: The author

Extended data - Assent form

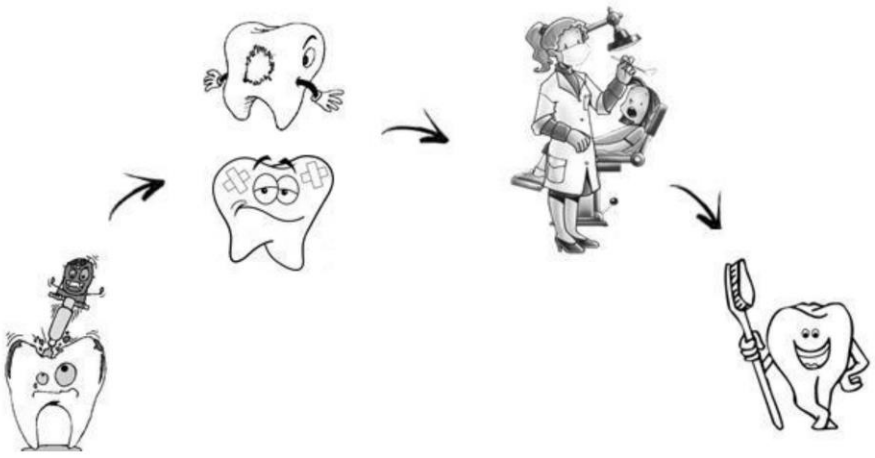
Assent Form

Some time ago, you made a filling in your tooth because bacteria made a little hole to live inside it. In this research, a dentist will look if this filling is still beautiful or if it is necessary to do a new one.

Another dentist will also clean your teeth and look at your mouth to see if the bacteria has returned and made new cavities in other teeth. The dentists will use a plane buccal mirror, dental tweezer, a probe with a small ball at the end, cotton, rotating bristle brush, toothbrush, and toothpaste. We will show everything to you so that you will be familiar with all the dentist's stuff.

If the dentist finds new bacteria's houses or if any of your fillings are old and need to be changed, other dentists will take care of you and your teeth, so that you get healthier and send all the bacteria out of your mouth.

Let's take care of your toothy?



If you agree to receive the dental care described in the text above, write your name on the line below.

_____

Source: The author

Extended data - Assent form in the original language (Portuguese)

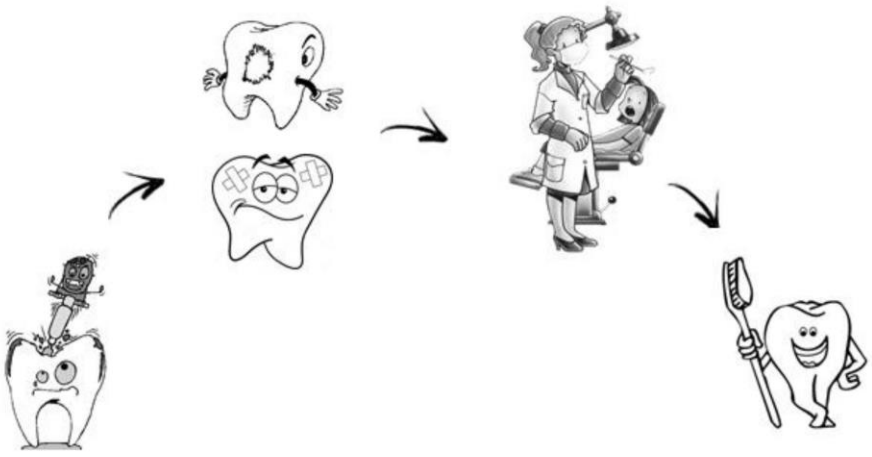
Termo de Assentimento

Há um tempo atrás, você precisou colocar uma massinha no seu dente porque o bichinho da cárie fez um buraquinho para morar dentro dele. Nesta pesquisa uma dentista irá olhar se essa massinha ainda está bonita ou se é preciso colocar uma massinha nova no lugar dessa.

Uma outra dentista também irá limpar os seus dentes e olhar sua boca para ver se o bichinho voltou e fez novos buraquinhos em outros dentes. Os materiais que as dentistas podem usar para ajudar a enxergar melhor a massinha e os buraquinhos são: espelho, pinça, uma sonda com bolinha na ponta, algodão, motorzinho, escova e pasta de dente. Tudo isso será mostrado pra você antes de ser usado, para que você conheça todos os materiais do dentista.

Se as dentistas encontrarem novas casinhas de bichinho ou se as massinhas que você tem estiverem velhas e precisarem ser trocadas, outros dentistas irão cuidar de você e dos seus dentes, para que você fique mais saudável e mande todos os bichinhos embora da sua boca.

Vamos cuidar do seu dentinho?



Se você concordar em receber o tratamento descrito neste texto acima, escreva seu nome na linha abaixo.

_____

Source: The author

Extended data - Restorations assessment form

RESTORATION ASSESSMENT

DATE: **TIME SPENT IN THE ASSESSMENT:** ☐ CARS ☐ FDI

1.PATIENT IDENTIFICATION:

Name:_____

	Tooth	Surfaces	Restorative Material	FDI				Repair more or less than 1mm
				Marginal staining	Marginal adaptation	Recurrence of caries	Treatment decision	
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								

Source: The author

RESTORATION ASSESSMENT

DATE: **TIME SPENT IN THE ASSESSMENT:** ☐ CARS ☐ FDI

1.PATIENT IDENTIFICATION:

Name:_____

	Tooth	Surfaces	Restorative Material	CARS			Repair more or less than 1mm
				Code	Activity status	Treatment decision	
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							

Source: The author

Extended data - Restorations assessment form in the original language (Portuguese)

AVALIAÇÃO DAS RESTAURAÇÕES

DATA: **TEMPO DA CONSULTA:** ☐ CARS ☐ FDI

1.IDENTIFICAÇÃO DO PACIENTE:

Nome:_____

	Dente	Superfícies	Material	FDI				Reparo maior ou menor 1mm
				Manc. marginal	Adaptação marginal	Cárie recorrente	Tratamento	
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								

Source: The author

AVALIAÇÃO DAS RESTAURAÇÕES

DATA: **TEMPO DA CONSULTA:** ☐ CARS ☐ FDI

1.IDENTIFICAÇÃO DO PACIENTE:

Nome:_____

	Dente	Superfícies	Material	CARS			Reparo maior ou menor 1mm
				Código	Atividade	Tratamento	
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							

Source: The author

Extended data - Anamnesis form

Anamnesis Form

Child's legal name: _____ Date of birth: _____
Address/phone: _____

Dental History

Has your child been treated by another dentist: ( ) yes ( ) no
Child's age when first visited the dentist: _____
Reason to look at dental treatment: _____
Has your child ever had an anesthetic? ( ) yes ( ) no ( ) do not know
Has your child ever had a reaction to an anesthetic? ( ) yes ( ) no ( ) do not know
Recurrent mouth sores: ( ) yes ( ) no ( ) do not know
Recurrent fever blister: ( ) yes ( ) no ( ) do not know

Oral hygiene habits

Do you brush your child´s teeth? ( ) yes ( ) no
How often does your child brush his/her teeth? _____
Which toothpaste does he/she use? _____
Does he/she use dental floss? ( ) yes ( ) no ( ) occasionally

Deleterious oral habits

( ) sucking pacifier ( ) sucking finger ( ) chewing fingernails ( ) biting on objects
( ) grinding of teeth ( ) lip biting ( ) lingual interposition
How often: _____

Medical History

Does the child have any health problems? ( ) yes ( ) no
Which one? _____
Is your child being treated by a physician at this time? ( ) yes ( ) no
Is your child taking any medication? _____
Has your child had surgery? ( ) tonsils ( ) adenoid ( ) others: _____
Is your child allergic to: ( ) medicines ( ) latex ( ) foods ( ) others: _____
Does your child had or have one of the following problems:
( ) excessive bleeding ( ) convulsion ( ) diabetes ( ) heart defect/disease
( ) childhood diseases which one: _____
( ) breathing problems which one: _____

Soft Tissue Examination

Lips: _____ Buccal mucosa: _____ Tongue: _____
Labial frenulum: _____ Lingual frenulum: _____
Anomalies: _____

I declare all the above answers to be correct and true to the best of my knowledge and belief
Date:

_____
Signature of parent/guardian

Source: The author

Extended data - Anamnesis form in the original language (Portuguese)

Ficha de Anamnese

Nome:_____ Data:_____
Endereço: _____
Bairro:_____ Cep:_____

História Odontológica

Já foi ao dentista: ( ) sim ( ) não Idade da 1ª visita:_____
Por que procurou o dentista: _____
Já foi anestesiado (anestesia local)?: ( ) sim ( ) não ( ) não sei
Teve reação: ( ) sim ( ) não ( ) não sei
Aftas frequentes: ( ) sim ( ) não ( ) não sei Herpes frequentes: ( ) sim ( ) não ( ) não sei

Hábitos de Higiene

Você higieniza os dentes do seu filho: ( ) sim ( ) não
Quantas vezes:_____ Qual creme dental ? _____
Usa fio dental: ( ) sim ( ) não ( ) às vezes

Hábitos nocivos

( ) Chupeta ( ) Dedo ( ) rói unha ( ) morde objetos ( ) range dentes
( ) morde lábios ( ) interposição lingual Freqüência:_____

Histórico médico

Problemas com a saúde da criança: ( ) sim ( ) não
Qual? _____
Está em tratamento médico: ( ) sim ( ) não
Medicamentos em uso: _____
Intervenções cirúrgicas: ( )amígdalas ( ) adenóide ( ) outras:_____
Alergia a: ( ) medicamentos ( ) látex ( ) alimentos ( ) outros: _____
Teve ou tem um dos problemas abaixo:
( ) hemorragia ( ) convulsão ( ) diabete ( ) problema cardíaco
( ) doenças da infância Quais: _____
( ) problemas respiratórios Quais: _____

Exames tecidos moles

Lábios: _____ Bochechas: _____ Língua: _____
Freio labial: _____ Freio lingual: _____ anomalias: _____

Declaro que as respostas acima são verdadeiras
São Paulo, de de

_____
Assinatura do responsável

Source: The author

Extended data - Time and cost form

Patient: _____

Dentist/Dental auxilliary: _____

CARDEC - 3 | **Session nº** ____

Date	Procedure	Time

DISPOSABLES	
70% Alcohol **(50 ml)**	
Bibs **(unit)**	
Straw **(1/3 unit)**	
Coffee cup **(unit)**	
Wooden tongue depressor **(unit)**	
Cling Film **(30 cm)**	
Autoclave tape **(1 cm)**	
Gloves **(1 pair)**	
Mask **(unit)**	
Protective eyewear **(unit)**	
Cotton Rolls **(unit)**	
Syringe sleeve **(unit)**	
Plastic clear gloves **(1 pair)**	
Saliva ejector **(unit)**	
Cap **(unit)**	

PROPHY & EXAMINATION	
Mouth prop **(unit)**	
Cheek retractor **(unit)**	
Toothbrush **(unit)**	
Prophy brush **(unit)**	
Mirror **(unit)**	
Disclosing dye - Replak **(drop)**	
Floss **(10 cm)**	
Examination kit (mouth mirror, probe, tweezers)	
Prophy paste **(1 cm)**	
Pumice powder **(1 portion)**	
Dappen dish **(unit)**	
Periodontal curettes **(unit)**	
Prophy cup **(unit)**	

ANESTHETICS & ISOLATION	
Short needle **(unit)**	
Ultra-short needle **(unit)**	
Ainsworth rubber dam punch **(unit)**	
Anesthetic cartridge **(unit)**	
Topical anesthetic **(1 cm)**	
Ostby dam frame **(unit)**	
Dam clamp **(unit)**	
Dental dam **(unit)**	
Rubber dam fórceps **(unit)**	
Cartridge syringe **(unit)**	

SURGERY	
Elevator **(unit)**	
Blade **(unit)**	
Scalpel Handle **(unit)**	
Molt periosteal **(unit)**	
7 wax spatula **(unit)**	
Suture **(unit)**	
Forceps **(unit)**	
Gauze **(1 swab)**	
Carver Hollenbach **(unit)**	
Needle holder **(unit)**	
Saline water **(ml)**	
Seringa descartável **(unit)**	
Scissors **(unit)**	

TOPICAL FLUORIDE APPLICATION	
Duraphat **(1 cm)**	
Wooden tongue depressor **(unit)**	
Fluoride gel **(portion)**	
Micro applicators **(unit)**	
Fluoride tray **(unit)**	

X-RAY MATERIALS	
Film hanger **(unit)**	
Fixer **(50 ml)**	
Periapical X-ray film **(unit)**	
Child X-ray film **(unit)**	
Film holders **(set)**	
Developer **(50 ml)**	

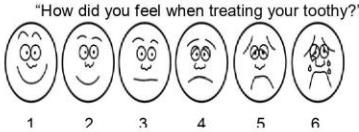
RESTORATIVES	
Polyacrilic acid **(drop)**	
Phosphoric acid **(1 cm)**	
Single Bond Universal Adhesive **(drop)**	
Round bur **(unit)**	
Excavator **(unit)**	
Wooden wedges **(unit)**	
Spatula no. 1 **(unity)**	
Carver Hollenbach **(unit)**	
Matrix strip - 5mm **(1 cm)**	
Matrix strip - 7 mm **(1 cm)**	
Micro applicators **(unit)**	
Dappen dish **(unit)**	
Bulk Fill Restorative **(increment)**	
Bulk Fill Flow **(increment)**	
Z350 XT restorative **(increment)**	
Riva Self Cure encaps. **(unit)**	
Tira de poliéster **(1/2 unit)**	
Petroleum jelly (**1cm**)	

FINISHING & POLISHING	
Diamond bur **(unit)**	
Polishing discs **(unit)**	
Carbon film paper **(1/3 unit)**	
Polishing strips **(unit)**	
Abrasive polishing strips **(1/2 unit)**	

Dentist, how was the child's behavior during the procedure?

( ) A lot of difficulties
( ) Some difficulty
( ) Indifferent
( ) Cooperated reasonably
( ) Cooperated well

WONG-BAKER FACIAL SCALE
"How did you feel when treating your toothy?".



Decayed tissue
Tooth: _____
☐ None
☐ Soft
☐ Hard

Restoration replacement:
Decayed tissue underneath the old restoration:
☐ None
☐ Soft
☐ Hard

Indirect costs
Transportation: ( ) Walk ( ) Bus ( ) Car ( ) Motorcycle ( ) Subway
Relatives' absenteeism in the workplace ( ) No ( ) Yes. Earnings loss during the appointment? _____

Source: The author

Extended data - Time and cost form in the original language (Portuguese)

Nome do paciente: _____

Dentista/auxiliar: _____

CARDEC - 3 | **Sessão nº** ___

TEMPO E CUSTO DOS PROCEDIMENTOS

Data	Procedimento	Tempo (s)

DESCARTÁVEIS	
Álcool 70 **(50 ml)**	
Babador **(unidade)**	
Canudo p/ tríplice **(1/3 unidade)**	
Espátula de madeira **(unidade)**	
Filme PVC **(30 cm)**	
Fita crepe **(1 cm)**	
Luva descartável **(1 par)**	
Máscara descartável **(unidade)**	
Óculos de proteção **(unidade)**	
Rolete de algodão **(unidade)**	
Saco de geladinho **(unidade)**	
Sobreluva **(unidade)**	
Sugador **(unidade)**	
Touca descartável **(unidade)**	

PROFILAXIA E EXAME CLÍNICO	
Abridor de boca **(unidade)**	
Afastador labial **(unidade)**	
Escova de dente **(unidade)**	
Escova de Robson **(unidade)**	
Espelho de mão OHB **(unidade)**	
Evidenciador Replak **(gota)**	
Fio dental **(10 cm)**	
Jogo clínico (pinça, espelho e sonda)	
Pasta profilática **(1 cm)**	
Pedra pomes **(1 porção)**	
Pote Dappen **(unidade)**	
Raspador periodontal **(unidade)**	
Taça de borracha **(unidade)**	

ANESTESIA E ISOLAMENTO	
Agulha curta **(unidade)**	
Agulha extra curta **(unidade)**	
Alicate perfurador de Ainsworth	
Anestésico **(tubete)**	
Anestésico tópico **(1 cm)**	
Arco de Young **(unidade)**	
Grampo isolamento **(unidade)**	
Lençol de borracha **(unidade)**	
Pinça porta-grampo de Palmer	
Seringa carpule **(unidade)**	

CIRURGIA	
Alavanca **(unidade)**	
Bisturi **(unidade)**	
Cabo para bisturi **(unidade)**	
Descolador de Molt **(unidade)**	
Espátula nº7 (unidade)	
Fio de sutura **(unidade)**	
Fórceps **(unidade)**	
Gaze **(1 compressa)**	
Hollemback **(unidade)**	
Porta agulha **(unidade)**	
Soro fisiológico **(unidade)**	
Seringa descartável **(unidade)**	

FLÚOR	
Duraphat **(1 cm)**	
Espátula de madeira **(unidade)**	
Flúor gel **(porção)**	
Microbrush **(unidade)**	
Moldeira para flúor **(unidade)**	

RADIOGRAFIA	
Colgadura **(unidade)**	
Fixador **(50 ml)**	
Película raio-x adulto **(unidade)**	
Película raio-x infantil **(unidade)**	
Posicionador radiográfico **(jogo)**	
Revelador **(50 ml)**	

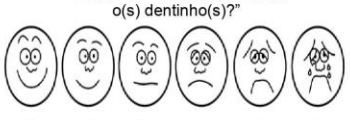
MATERIAIS RESTAURADORES	
Ácido poliacrílico **(gota)**	
Adesivo Single Bond Universal **(gota)**	
Broca esférica **(unidade)**	
Colher de dentina **(unidade)**	
Cunha de madeira **(unidade)**	
Espátula de inserção nº1	
Hollemback **(unidade)**	
Matriz 5 mm **(1 cm)**	
Matriz 7 mm **(1 cm)**	
Microbrush **(unidade)**	
Pote dappen **(unidade)**	
Resina Bulk Fill **(incremento)**	
Resina Bulk Fill Flow **(incremento)**	
Resina Z350 XT **(incremento)**	
Riva Self Cure encaps. **(unidade)**	
Tira de poliéster **(1/2 unidade)**	
Vaselina **(1cm)**	

ACABAMENTO E POLIMENTO	
Broca diamantada **(unidade)**	
Disco de acabamento **(unidade)**	
Papel carbono **(1/3 folha)**	
Tira de acabamento **(unidade)**	
Tira de lixa de aço **(1/2 unidade)**	

Dentista, como a criança reagiu nesta sessão?

( ) Criou muita dificuldade
( ) Criou alguma dificuldade
( ) Indiferente
( ) Cooperou razoavelmente
( ) Cooperou bem

DESCONFORTO
"Como você se sentiu ao tratar o(s) dentinho(s)?"



Tecido cariado do dente _____ :
- ☐ Ausente
- ☐ Amolecido
- ☐ Endurecido

Em caso de **substituição**, o tecido cariado **embaixo** da restauração antiga estava:
- ☐ Ausente
- ☐ Amolecido
- ☐ Endurecido

Custo
Meio de transporte usado para comparecer à consulta? ( ) A pé ( ) Ônibus ( ) Carro ( ) Moto ( ) Metrô
O responsável precisou faltar ao trabalho? ( ) Não ( ) Sim. Vai ser descontado do salário? _____

Source: The author

Extended data - SPIRIT checklist

SPIRIT Checklist: Recommended items to address in a clinical trial protocol and related documents*

Section/item	Item No	Description	Addressed on section/figure
Administrative information			
Title	1	Descriptive title identifying the study design, population, interventions, and, if applicable, trial acronym	Title page
Trial registration	2a	Trial identifier and registry name. If not yet registered, name of intended registry	Abstract
	2b	All items from the World Health Organization Trial Registration Data Set	n/a
Protocol version	3	Date and version identifier	Abstract
Funding	4	Sources and types of financial, material, and other support	Grant information
Roles and responsibilities	5a	Names, affiliations, and roles of protocol contributors	Title page
	5b	Name and contact information for the trial sponsor	Title page
	5c	Role of study sponsor and funders, if any, in study design; collection, management, analysis, and interpretation of data; writing of the report; and the decision to submit the report for publication, including whether they will have ultimate authority over any of these activities	Grant information
	5d	Composition, roles, and responsibilities of the coordinating centre, steering committee, endpoint adjudication committee, data management team, and other individuals or groups overseeing the trial, if applicable (see Item 21a for data monitoring committee)	Author contribution(s)
Introduction			
Background and rationale	6a	Description of research question and justification for undertaking the trial, including summary of relevant studies (published and unpublished) examining benefits and harms for each intervention	Introduction
	6b	Explanation for choice of comparators	Introduction
Objectives	7	Specific objectives or hypotheses	Introduction
Trial design	8	Description of trial design including type of trial (eg, parallel group, crossover, factorial, single group), allocation ratio, and framework (eg, superiority, equivalence, noninferiority, exploratory)	Methods
Methods: Participants, interventions, and outcomes			
Study setting	9	Description of study settings (eg, community clinic, academic hospital) and list of countries where data will be collected. Reference to where list of study sites can be obtained	Study setting
Eligibility criteria	10	Inclusion and exclusion criteria for participants. If applicable, eligibility criteria for study centres and individuals who will perform the interventions (eg, surgeons, psychotherapists)	Participant eligibility
Interventions	11a	Interventions for each group with sufficient detail to allow replication, including how and when they will be administered	Interventions
	11b	Criteria for discontinuing or modifying allocated interventions for a given trial participant (eg, drug dose change in response to harms, participant request, or improving/worsening disease)	Interventions
	11c	Strategies to improve adherence to intervention protocols, and any procedures for monitoring adherence (eg, drug tablet return, laboratory tests)	Adherence
	11d	Relevant concomitant care and interventions that are permitted or prohibited during the trial	Dental treatment protocols and Figure 1
Outcomes	12	Primary, secondary, and other outcomes, including the specific measurement variable (eg, systolic blood pressure), analysis metric (eg, change from baseline, final value, time to event), method of aggregation (eg, median, proportion), and time point for each outcome. Explanation of the clinical relevance of chosen efficacy and harm outcomes is strongly recommended	Outcomes

Participant timeline	13	Time schedule of enrolment, interventions (including any run-ins and washouts), assessments, and visits for participants. A schematic diagram is highly recommended (see Figure)	Participant recruitment and timeline and Figure 2
Sample size	14	Estimated number of participants needed to achieve study objectives and how it was determined, including clinical and statistical assumptions supporting any sample size calculations	Sample size
Recruitment	15	Strategies for achieving adequate participant enrolment to reach target sample size	Study setting
Methods: Assignment of interventions (for controlled trials)			
Allocation:			
Sequence generation	16a	Method of generating the allocation sequence (eg, computer-generated random numbers), and list of any factors for stratification. To reduce predictability of a random sequence, details of any planned restriction (eg, blocking) should be provided in a separate document that is unavailable to those who enrol participants or assign interventions	Allocation: sequence generation and concealment mechanism
Allocation concealment mechanism	16b	Mechanism of implementing the allocation sequence (eg, central telephone; sequentially numbered, opaque, sealed envelopes), describing any steps to conceal the sequence until interventions are assigned	Allocation: sequence generation and concealment mechanism
Implementation	16c	Who will generate the allocation sequence, who will enrol participants, and who will assign participants to interventions	Allocation: sequence generation and concealment mechanism
Blinding (masking)	17a	Who will be blinded after assignment to interventions (eg, trial participants, care providers, outcome assessors, data analysts), and how	Methods
	17b	If blinded, circumstances under which unblinding is permissible, and procedure for revealing a participant's allocated intervention during the trial	n/a
Methods: Data collection, management, and analysis			
Data collection methods	18a	Plans for assessment and collection of outcome, baseline, and other trial data, including any related processes to promote data quality (eg, duplicate measurements, training of assessors) and a description of study instruments (eg, questionnaires, laboratory tests) along with their reliability and validity, if known. Reference to where data collection forms can be found, if not in the protocol	Interventions, Dental treatment protocols, Follow-up visits, Time and cost form, Restorations assessment form
	18b	Plans to promote participant retention and complete follow-up, including list of any outcome data to be collected for participants who discontinue or deviate from intervention protocols	Outcomes
Data management	19	Plans for data entry, coding, security, and storage, including any related processes to promote data quality (eg, double data entry; range checks for data values). Reference to where details of data management procedures can be found, if not in the protocol	Data management
Statistical methods	20a	Statistical methods for analysing primary and secondary outcomes. Reference to where other details of the statistical analysis plan can be found, if not in the protocol	Statistical methods
	20b	Methods for any additional analyses (eg, subgroup and adjusted analyses)	n/a
	20c	Definition of analysis population relating to protocol non-adherence (eg, as randomised analysis), and any statistical methods to handle missing data (eg, multiple imputation)	n/a
Methods: Monitoring			
Data monitoring	21a	Composition of data monitoring committee (DMC); summary of its role and reporting structure; statement of whether it is independent from the sponsor and competing interests; and reference to where further details about its charter can be found, if not in the protocol. Alternatively, an explanation of why a DMC is not needed	Data monitoring

	21b	Description of any interim analyses and stopping guidelines, including who will have access to these interim results and make the final decision to terminate the trial	Data monitoring
Harms	22	Plans for collecting, assessing, reporting, and managing solicited and spontaneously reported adverse events and other unintended effects of trial interventions or trial conduct	Harms
Auditing	23	Frequency and procedures for auditing trial conduct, if any, and whether the process will be independent from investigators and the sponsor	Auditing
Ethics and dissemination			
Research ethics approval	24	Plans for seeking research ethics committee/institutional review board (REC/IRB) approval	Methods
Protocol amendments	25	Plans for communicating important protocol modifications (eg, changes to eligibility criteria, outcomes, analyses) to relevant parties (eg, investigators, REC/IRBs, trial participants, trial registries, journals, regulators)	n/a
Consent or assent	26a	Who will obtain informed consent or assent from potential trial participants or authorised surrogates, and how (see Item 32)	Study setting
	26b	Additional consent provisions for collection and use of participant data and biological specimens in ancillary studies, if applicable	n/a
Confidentiality	27	How personal information about potential and enrolled participants will be collected, shared, and maintained in order to protect confidentiality before, during, and after the trial	Confidentiality
Declaration of interests	28	Financial and other competing interests for principal investigators for the overall trial and each study site	Competing interests
Access to data	29	Statement of who will have access to the final trial dataset, and disclosure of contractual agreements that limit such access for investigators	Access to data
Ancillary and post-trial care	30	Provisions, if any, for ancillary and post-trial care, and for compensation to those who suffer harm from trial participation	Ancillary and post-trial care
Dissemination policy	31a	Plans for investigators and sponsor to communicate trial results to participants, healthcare professionals, the public, and other relevant groups (eg, via publication, reporting in results databases, or other data sharing arrangements), including any publication restrictions	Dissemination policy
	31b	Authorship eligibility guidelines and any intended use of professional writers	Dissemination policy
	31c	Plans, if any, for granting public access to the full protocol, participant-level dataset, and statistical code	Dissemination policy
Appendices			
Informed consent materials	32	Model consent form and other related documentation given to participants and authorised surrogates	n/a
Biological specimens	33	Plans for collection, laboratory evaluation, and storage of biological specimens for genetic or molecular analysis in the current trial and for future use in ancillary studies, if applicable	n/a

*It is strongly recommended that this checklist be read in conjunction with the SPIRIT 2013 Explanation & Elaboration for important clarification on the items. Amendments to the protocol should be tracked and dated. The SPIRIT checklist is copyrighted by the SPIRIT Group under the Creative Commons "Attribution-NonCommercial-NoDerivs 3.0 Unported" license.

4 CHAPTER II: CROSS-SECTIONAL STUDY

Influence of different clinical criteria on the decision to replace restorations in primary teeth

Short title: Restoration replacement decision-making

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Keywords: Diagnosis. Visual Inspection. Dental Caries. Dental Restoration, Permanent. Repair. Clinical Study.

Influence of different clinical criteria on the decision to replace restorations in primary teeth

Abstract

Objectives: This cross-sectional study is nested in a randomized clinical trial. It was designed to evaluate the influence of using two different clinical criteria to assess caries lesion around restorations on the decision to replace restorations in primary posterior teeth. Variables that might influence this decision were also considered.

Methods: One trained and calibrated examiner assessed 550 restorations of 160 children (3-10 years old). Children were randomized to have their restorations evaluated and subsequently treated according to World Dental Federation (FDI) or Caries Associated with Restorations and Sealants (CARS) criteria. After reaching the treatment decision, the same examiner performed another evaluation using the other criteria. Spearman's correlation coefficients and 95% confidence intervals (95%CI) between the scores obtained with both criteria and respective treatment decisions were calculated. Poisson multilevel regression analysis were performed between the exploratory variables related to children, restored tooth and restoration assessment; the outcome variables were decisions related to restoration replacement, any operative intervention and presence of secondary caries.

Results: The strongest correlation observed between the methods was for recurrence of caries. A total of 94 restorations (17.1%) were indicated for replacement with FDI criteria and 30 (5.5%) were indicated for replacement with CARS. Besides the diagnostic method used, number of decayed teeth and restorations with two and three restored surfaces were associated with the decision of replacement and presence of recurrent caries lesions.

Conclusions: The decision to replace posterior restorations in primary teeth is influenced by the criteria used for the restorations assessment and also by the children's caries experience and multisurface restorations. The restoration material did not influence the decision of restorations replacement.

Clinical Significance: The decision to replace posterior restoration in primary teeth is strongly related to the evaluation method and not only by patients' risk factors.

4.1 Introduction

Restorations replacement is one of the most performed procedures carried out by dentists in public and private practices [1, 2]. Current data estimate that 58% of restorations performed by clinicians are actually replacements of existing restorations and not a new procedure in cavitated caries lesions [3]. However, this procedure often causes the loss of healthy dental structure [2-4] leading to a repeated restorative cycle [5]. As a consequence, there is also an increase in professional clinical time, as well as the financial costs for health systems [2]. To minimize these consequences and to increase the longevity of the defective restorations, minimal intervention procedures have been proposed as the repair and the refurbishment [6]. Although repaired restorations were more likely to receive additional treatment compared to replaced restorations, repairs lead to a lower index of more aggressive treatments such as endodontic or tooth extraction [7].

Several reasons for failure and replacement of restorations have been reported. The main reason is caries lesions around restorations [8], also called “secondary caries” or “recurrent caries”. Contrary to the common-sense, the material exerts only a minor effect on the necessity of replacing a restoration in permanent teeth [9]. Factors related to the failure of restorations in adults are patients’ caries risk [2, 10-12], occlusal stress [12], number of restored surfaces [11], and tooth type and arch [12]. On the other hand, in primary teeth, the restorative material [13] and other treatment-related factors [14] seemed to have a stronger influence on restoration replacement. Moreover, restorations made in children with higher caries risk were also more probable to be replaced [13-15].

Besides those variables associated with the necessity of replacement of restorations, factors related to the diagnostic procedure might exert influence on this decision. Visual and radiographic methods are the most used methods to evaluate dental restorations for failures and presence of caries lesions [8]. However, this diagnostic process is not based on objective clinical criteria and there is a considerable variation in the methods used [8, 16]. As a consequence, clinicians are more prone to cofound small defects of the restorations (staining, for example) with caries lesions [17], which can lead to a potential overtreatment [3].

To minimize this consequence and to promote greater objectivity to the diagnosis of caries lesions around restorations, some clinical criteria have been proposed to be used in research and in the clinical practice. Two examples are the criteria developed by the International Dental Federation (FDI) [18], and the Caries Associated with Restorations and Sealants (CARS), which has been integrated into the International Caries Classification and Management System (ICCMS) [19], and its more recent update, named CariesCare 4D [20]. However, the accuracy of these systems and other methods have been poorly investigated, mainly in primary teeth [8, 16]. Moreover, the impact of the use of these criteria on the decision to replace restorations has not been evaluated yet. It would be important that the method for assessing dental restorations is in line with the current philosophy of minimal intervention [21, 22].

Therefore, the aim of this paper is to evaluate if two different visual criteria for restorations evaluation, the FDI and CARS criteria, might influence the replacement decision-making of restorations in primary teeth. Our working hypothesis is that, besides other variables, the diagnostic strategy to evaluate the restorations also influences the decision of replacement. Other objectives were to investigate the differences between the visual methods concerning the detection of caries lesions around restorations in primary teeth and considering the decision for any type of treatment.

4.2 Materials and Methods

Study Design, Ethics Approval, Setting and Participant Selection

This is a cross-sectional study conducted a Dental School. We followed the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) statement to write the manuscript. The local committee for ethics in research approved the protocol. Written informed consent was obtained from all the parents/caregivers, and assent form was signed by literate children.

This research is nested within a clinical trial performed to test different diagnostic strategies for the assessment of restorations in primary teeth. The main clinical trial, named Caries Detection in Children nº 3 (CARDEC-3), is registered at the platform Clinicaltrials.gov (NCT03520309).

Briefly, the abovementioned clinical trial was designed to compare the impact of two different diagnostic strategies and consequent treatment in the long-term success of restorations placed in primary teeth. Children aged 3 to 10 years, who sought dental treatment in our dental school, were randomly selected from a pool of enrolment forms, from November 2017 to November 2018. Therefore, the study was conducted in a dental office setting. Participants were randomly allocated in two groups according to the diagnostic strategy used. One group of participants corresponded to patients who received diagnosis and treatment decision according to FDI criteria [18] (FDI group). The other group of participants received diagnosis and treatment decision according to CARS criteria from ICCMS [19] (CARS group). Then, the children are being followed-up for two years, and the primary endpoint is the longevity of the restoration. More details on the clinical trial can be accessed in the clinicaltrials.gov platform.

The inclusion criteria were children: (1) who sought dental treatment at the School of Dentistry; (2) from 3 to 10 years old; (3) with at least one restoration on a primary tooth of any material (composite resin, amalgam or glass ionomer cement), on anterior or posterior primary tooth. The exclusion criteria were children: (1) whose parents did not agree to participate in the study; (2) who had behavioral problems during the initial appointment.

All children's teeth presenting restorations were included in the evaluation, except restored teeth presenting signs or symptoms of pulp involvement (fistula, abscess, pulp exposure, history of spontaneous dental pain) or mobility. Children presenting these conditions in one or more teeth, but also presenting at least one eligible tooth fitting the inclusion criteria were still included in the study.

At the end of the first appointment, dietary advice and oral hygiene instructions were delivered, showing the correct use of toothbrush and fluoride toothpaste (1000 to 1500 ppm of fluoride) to all children and their parents or legal guardians.

Explanatory Variables and Outcomes

The main explanatory variable was the diagnostic strategy used to assess the restorations placed in primary teeth: FDI or CARS criteria. A trained and calibrated examiner assessed all restorations. The calibration processes involved theoretical classes about both clinical criteria and training with photos of clinical cases through

the web-based training and calibration tool called e-calib (www.e-calib.info) and through the e-learning from ICCMS (https://www.iccms-web.com). After these procedures, the examiner evaluated restorations in 10 patients and repeated the same evaluation for intra-examiner agreement. A benchmark examiner also performed the tests to evaluate interexaminer reproducibility. The evaluations in the children included in the study began only when the intra-examiner and inter-examiner weighted kappa value reached values greater than 0.75 with both FDI and CARS criteria.

The examinations were conducted on a dental chair under illumination after the teeth had been cleaned with rotating bristle brush, pumice/water slurry, and dental floss. The evaluation was performed with a plane buccal mirror and a ball-point probe. For the exam performed with the FDI criteria, all surfaces were dried before the evaluation. In the assessment of restorations performed with CARS criteria, the teeth were evaluated wet and then were dried for 5 seconds with a 3-in-1 syringe.

Restoration's evaluation was first performed with the participant's allocated group considering the clinical trial. After reaching the diagnosis and treatment decision, the same examiner performed a second evaluation according to other criteria. This procedure was conducted only to compare the methods of the study and the second evaluation did not influence the classification and treatment decision proposed by the first criteria which the participant was allocated.

The two diagnostic criteria were:

- FDI: diagnosis and treatment decision based on the International Dental Federation (FDI) criteria [18]
- CARS: diagnosis and treatment decision according to CARS (Caries Associated with Restorations or Sealants) detection criteria, described in the ICCMS and in CariesCare 4D [19, 20]

Originally, the FDI system is based in three different categories: aesthetic, functional and biological. Each category is divided into subcategories totalizing sixteen evaluated aspects. Each subcategory is scored according to a five-step grading of the restoration. The restoration final score is the highest score obtained among all categories. However, for our study we selected three subcategories to use among the FDI criteria: marginal staining, marginal adaptation and recurrence of

caries. According to the FDI authors, researchers do not have to use necessarily all sixteen subcategories but should select the most suitable according to the study [18, 23]. The detailed description of the FDI criteria categories used in our study are presented in the Appendix A in Supplementary material.

The CARS criteria were derived from the International Caries Detection and Assessment System (ICDAS), and it has been the criteria proposed in the ICCMS and the updated CariesCare International 4D [19, 20] (Appendix B in Supplementary material). The definitions and characteristics of active and inactive lesions for primary caries evaluation from CariesCare International 4D (Appendix C of the Supplemental material) were also used in association with CARS criteria in this study [20]. However, as this system does not define a treatment decision linked to the CARS classification, we adapted the decisions based on the recommendations for the treatment of primary caries lesions. This treatment decision matrix is presented at the Appendix D (Supplementary file).

The treatment decisions for the restorations evaluated according to the FDI and CARS criteria were classified into: no treatment (without necessary intervention and follow-up of the restoration over time), professional topical fluoride application (as a treatment for non-cavitated active caries lesions detected by the CARS criteria), refurbishment (finishing and polishing of the restoration), repair (minimally invasive approach that implies in any case the addition of a restorative material, with or without a preparation in the restoration and/or dental hard tissues) [23] and replacement (complete removal of the restoration) [23].

The explanatory variables were related to three different levels: children (3rd level), restored teeth (2nd level) and clinical evaluation (1st level). The main exposure (method for the assessment of the restoration) is related to the 1st level (FDI or CARS method). Another variable related to the 1st level was the order that the diagnostic method was performed. Explanatory variables related to the teeth were: Dental arch (upper or lower), number of restored surfaces (1 surface, 2 surfaces, 3 or more surfaces), and dental material (composite resin, glass-ionomer cement or amalgam). The variables related to the children (3rd level) were sex, age (3 to 6 years-old and 7 to 10 years-old), number of restorations (1 to 3 restorations or more than 3 restorations), number of decayed teeth (quantitative variable), number of filled teeth (quantitative variable), number of missed teeth (quantitative variable), dmf-t + DMF-T (quantitative variable).

The main outcome of this study was the decision to replace the restoration evaluated by the different criteria. Other outcomes were the decision of any operative intervention for the restorations (repair or replacement), and the presence of caries lesion around restorations defined by FDI or CARS criteria.

Sample size calculation and statistical analysis

The sample size calculation was based on the primary outcome of the randomized clinical trial, which was the percentage of restorations requiring reintervention. For the main clinical trial, the minimum sample size was 626 restored primary teeth. Thus, in the presented study, 1272 evaluations were conducted. Considering a two-sided 95% confidence interval (95%CI), a restoration replacement rate of around 16%, a prevalence ratio (PR) value of 1.5 as minimal clinically relevant difference, we had a statistical power of 81.9%.

For the data analysis, firstly, Spearman's rank correlation analyses were conducted between the scores obtained with CARS and FDI, in relation to marginal staining, marginal adaptation and presence of caries lesions, separately. With this approach, Spearman's correlation coefficient (Rho) and respective 95% CIs were calculated.

The treatment decisions regarding the restorations obtained with both FDI and CARS criteria were categorized into: (i) no treatment, (ii) repair or refurbishment, and (iii) replacement. Restorations that were classified as without intervention's need and those that were assigned to receive topical fluoride application were included in category (i). Spearman's correlation analysis was conducted, and the decisions were compared between the groups using Chi-square test, adjusted by the cluster.

Afterward, univariate and multiple Poisson multilevel regression analysis between the independent variables and the primary outcome (the indication of replacement of restorations), and PR values and 95%CIs were calculated. First, univariate analyses were carried out. Then, we conducted multiple regression analysis. For this analysis, the explanatory variables named diagnostic method, and dental material were inserted, regardless of the level of significance. The order of examinations was also included in all multiple models, to adjust the analysis considering a possible occurrence of incorporation bias, since the first method could exert an influence on

the second method. Other variables with p value <0.05 were also maintained in the final model.

Similar Poisson multilevel regression analyses were performed considering the other outcomes: indication of any type of treatment and presence of caries lesion. A significance level of 5% was considered for analyzes, and the statistical package Stata 13 (StataCorp LP, College Station, USA) was used.

4.3 Results

Of the 162 children who were invited, 160 (86 boys and 74 girls) completed all phases of this study. Two children were excluded because they presented behavioral problems during the examinations. The mean (Standard Deviation - SD) age of the sample was 7.0 (1.6) years. Of the included children, 61 (38.1%) had 1 to 3 restorations, while 99 (61.9%) had 4 or more restorations. The mean number (SD) of restorations of included children was 4.6 (2.6). The mean (SD) of the number of decayed or permanent decayed or lost teeth (dmf-t + DMF-T) of the study participants was 6.5 (3.4). All participants were submitted to both FDI and CARS diagnostic strategies for the evaluation of restorations. In 79 children (49.4%), CARS was first performed, and in 81 (50.6%) the first evaluation method was the FDI.

From a total of 636 restorations, being 86 (13.5%) were in anterior primary teeth and 550 in posterior teeth (86.5%). Due to the small number of restorations placed on anterior teeth, we decided to analyze only restorations placed in posterior teeth (550). Concerning the posterior restorations material, 401 (72.9%) were glass-ionomer cement, 129 (23.5%) were composite resin and 20 (3.6%) were amalgam. Single surface restorations corresponded to 228 (41.5%), 159 (28.9%) with two dental surfaces involved and 163 (29.6%) had 3 or more dental surfaces involved.

The relation between the scores obtained with the FDI and the CARS criteria considering staining, adaptation and presence of caries lesions around restorations are presented on table 1. The higher Rho value was observed between CARS and FDI methods regarding presence of caries lesions, followed by marginal adaptation, while marginal staining showed the weakest correlation (Table 1).

Considering the treatment decisions reached by FDI and CARS criteria, a high Rho value was obtained between the methods (Table 2). However, we noticed that FDI criteria led to a higher proportion of more invasive treatments. From 550

restorations, 94 (17.1%) were indicated for replacement with FDI criteria, while only 30 (5.5%) ones were indicated for replacement when evaluated with CARS method (Table 2). In addition, 62 restorations that would be repaired with CARS criteria indicated for replacement when evaluated with the FDI method (Table 2). A more invasive treatment decision was obtained only with 2 restorations evaluated with CARS criteria (Table 2). Differences among the type of treatments indicated were statistically significant ($p < 0.001$).

The adjusted Poisson multilevel regression analysis of the association among the explanatory variables and restoration's replacement showed that restorations evaluated by FDI criteria were three times more frequently indicated for replacement than when these restorations were assessed by CARS criteria (Table 3). A significant positive association between decayed teeth of the children and indication for restoration's replacement, independent of the evaluation criteria used, was also observed (Table 3). Restorations involving two surfaces had 96% higher proportion of replacement decision, and restorations with 3 or more surfaces had a two-fold higher proportion of replacement recommendation when compared to single surface restorations. The restorative material, on the other hand, did not exert influence on this recommendation (Table 3).

When considering the indication of any type of treatment for the restoration decided by the FDI and CARS criteria as outcome, the same trends were observed considering number of decayed teeth and number of surfaces restored (Table 4). However, the diagnostic method and dental material did not present significant association with the indication of any type of treatment (Table 4).

As regards the occurrence of dental caries, restorations assessed with the FDI method were more probable to be classified as having caries lesions than those assessed by CARS method (Table 5). We also observed that the children's number of decayed teeth and caries experience influenced the classification of caries lesions around restorations, independent of the method used for assessing the restorations (Table 5). Other variable significantly associated was the number of restored surfaces. The order of methods and the dental material were not significantly associated with the presence of caries around restorations (Table 5).

4.4 Discussion

Many reasons have been related to the recommendation for replacing restorations in primary and permanent teeth, such as children's caries risk [2,10-15], restorative dental material [13], number of restored surfaces [11] and occlusal stress [12]. Our study, for the first time, showed that the method used for the assessment of the restorations is an additional variable that can influence the decision to replace them, at least for primary teeth. We observed that the use of the FDI method led to indicate more invasive treatments than using the system proposed by the ICCMS [19] and its updated version, the CariesCare 4D [20]. This study represents the first evidence in the literature about the impact of the use of different diagnostic criteria on treatment decisions regarding the restorations in primary teeth.

Although significant differences were observed, we found a strong correlation between the criteria considering the presence of caries lesions around restorations. This high correlation when the presence of caries process is comprehensible, since the CARS criteria is mainly focused on caries lesions detection, and the characteristics related to the presence of caries described in the FDI criteria are very similar. A lower significant correlation was observed between the CARS criteria and the restoration's marginal adaptation evaluated by FDI criteria. This finding is also coherent since marginal defects, despite being questioned by some researchers, may predispose demineralization and lead to the development of caries lesions around restorations, as it was found in evidence from in vitro [24, 25] and in situ research [26]. Otherwise, the correlation between CARS and FDI methods regarding the marginal staining was very low. This finding is in line with the fact that staining around restorations does not predict the presence of caries [27], even being often mistakenly interpreted as initial secondary caries lesion leading to a possible overtreatment [16].

Regarding the treatment decisions recommended by the methods, the FDI criteria led to a more invasive treatment approach probably since the final score is given according to the most severe score obtained among all selected categories. For example, in restorations classified with deep marginal staining, but no gaps and no caries lesions, the treatment indicated by the FDI method would be the replacement of the restoration. However, it is not possible to assert a better diagnostic strategy with cross-sectional study design. This issue will be answered with the randomized

clinical trial which nests this study, the CARDEC-3. Although there is a lack of evidence towards the diagnosis and management of defective restorations in primary teeth, the minimal intervention approach for caries seems to result in better outcomes for the patients [28]. For this reason, future studies should consider other treatment options for the management of defective restorations. Among them, the Hall Technique could be considered rather than restoration replacement in certain situations.

Besides the advantage of a restoration presenting less chance of being replaced when evaluated with CARS, the criteria seem more suitable to describe the severity of secondary caries and aspects such as stained margins and amalgam shadows not consistent with caries lesions [2]. Moreover, when considering any type of treatment for restoration decided with FDI and CARS (repair or refurbishment, and replacement), the diagnostic method did not present significance in the analysis. This means that restorations evaluated with CARS also receive a considerable number of operative interventions, but less invasive conducts were prioritized instead of replacement. According to a recent consensus paper, before considering replacing a restoration, clinicians should consider monitoring, refurbishment, and repair as a better option [29]. However, according to our observations, CARS criteria may be suitable just for evaluating caries around restorations. The CARS criteria fail, for example, in indicating need of replacement due to restoration fracture or other major failures than presence of caries lesions.

As previously reported, clinical and patient-related risk factors for failure of restorations [2, 30] might also influence the dentists' restorative treatment decisions. In our study, we identified that restorations in children with higher number of decayed teeth and with more than one surface restored were more likely to have an indication of replacement. Many of these findings are corroborate in previous studies [2, 10-12, 14, 15, 30]. An increased risk of restoration failure in children with a higher caries experience was not surprising. Caries around restorations is primary caries at the margin of an existing filling [31]; hence, it is expected that the same risk factors are associated with both lesions. Other finding of our study is that the restorative material did not exert influence on this decision, differently from an earlier study [13]. Therefore, clinicians should focus on children's health-promoting to improve restorations longevity [2], diminishing replacement of restorations.

A limitation of the present study, however, is that the FDI method is usually indicated to be used in clinical studies [32, 33]. Our study, nevertheless, is evaluating the FDI method for clinical practice purposes. In fact, the original article describing the FDI method has already mentioned its importance for practitioners and dental students [18]. The CARS, on the other hand, was purposed mainly for clinicians, although it is possible to use it in clinical studies [19]. Nevertheless, both methods present some shortcomings regarding decisions for clinical practice in some situations. For example, the CARS method does not consider major fractures of the restorations. Thus, the methods should be updated, considering their use in the clinical practice since restoration loss and marginal adaptation are other reported reasons for restorations failure of clinical studies conducted in primary teeth with restorations of different materials and with at least one year of follow-up [34].

Therefore, considering the dental office setting, we observed that the method of evaluation of restored teeth influences the decision to replace dental restorations since the FDI method tended to indicate more replacements than the CARS method. The minimal intervention approach [22, 35] has demonstrated to be the best way to deal with the caries process in clinical practice. According to this philosophy, clinicians should repair rather than replace defective restorations to promote the preservation of sound structure [22, 36]. Therefore, the diagnostic strategy should also be in line with this. Nevertheless, although FDI criteria led to a higher proportion of restorations replacement in our study, the long-term impact of this trend will be only evaluated at the end of our clinical trial.

4.5 Conclusions

The diagnostic strategy used to evaluate posterior restorations in primary teeth influences the clinical decision-making for restoration replacement. In this way, FDI criteria suggest more invasive treatments when compared with the CARS method. Besides that, children’s caries experience and multisurface restorations influence the decision to replace restorations in primary teeth, but not the restorative dental material.

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Table 1 - Relationship among scores obtained with the International Dental Federation criteria (FDI), considering criteria for staining, adaptation and presence of caries lesions, and scores obtained with Caries Around Restorations System (CARS)

FDI criteria	**CARS criteria**							**Total**
	0	**1**	**2**	**3**	**4**	**5**	**6**	
FDI staining								
1	175	3	34	45	2	74	49	382
2	24	0	8	29	2	38	8	109
3	2	0	5	6	1	22	8	44
4	3	0	1	3	0	2	2	11
5	0	0	0	0	0	2	2	4
Rho = 0.246 (95% CI = 0.166 to 0.323)								
FDI adaptation								
1	110	1	10	8	1	2	0	132
2	44	1	17	22	0	0	1	85
3	32	1	19	39	4	8	1	104
4	16	0	1	14	0	105	12	148
5	2	0	1	0	0	23	55	81
Rho = 0.790 (95% CI = 0.756 to 0.820)								
FDI presence of caries lesions								
1	194	0	4	8	1	1	2	210
2	7	3	39	40	1	0	0	90
3	0	0	4	30	3	1	1	39
4	2	0	1	5	0	127	12	147
5	1	0	0	0	0	9	54	64
Rho = 0.926 (95% CI = 0.913 to 0.937)								
Total	**204**	**3**	**48**	**83**	**5**	**139**	**69**	**550**

Rho = Spearman correlation coefficient; 95% CI = 95% confidence interval

Source: The author

Table 2 - Relationship among treatment decision reached using the International Dental Federation criteria (FDI) and using Caries Around Restorations System (CARS)

FDI	CARS			Total
	No treatment	Repair	Replacement	
No treatment	285	9	0	294 (53.5%)
Repair	41	119	2	162 (29.5%)
Replacement	4	62	28	94 (17.1%)
Total	330 (60.0%)	190 (34.5%)	30 (5.5%)	550
Spearman correlation coefficient = 0.825 (95% Confidence interval = 0.796 to 0.850)				
Chi-square adjusted by the cluster = 56.10; $p < 0.001$				

Source: The author

Table 3 - Association among explanatory variables and restoration replacement (outcome) indicated by two different criteria system: International Dental Federation criteria (FDI) and using Caries Around Restorations System (CARS)

Explanatory variables	**Unadjusted PR (95%CI)**	**p**	**Adjusted PR (95%CI)**	**P**
Variables related to the children (3rd level)				
Sex (ref.: male)			*	
Female	0.78 (0.50 to 1.25)	0.306		
Age (ref.: 3 to 6 yrs-old)			*	
7 to 10 yrs-old	1.01 (0.64 to 1.61)	0.954		
Number of restorations (ref.: 1 to 3 restorations)			*	
More than 3 restorations	1.09 (0.63 to 1.88)	0.772		
Number of decayed teeth (quant.)	1.20 (1.07 to 1.35)	0.002	1.18 (1.05 to 1.33)	0.004
Number of filled teeth (quant.)	1.00 (0.91 to 1.09)	0.985	*	
Number of missed teeth (quant.)	0.90 (0.69 to 1.16)	0.406	*	
dmf-t + DMF-T	1.05 (0.98 to 1.13)	0.171	*	
Variables related to the restored tooth (2nd level)				
Dental arch (ref.: upper)			*	
Lower	0.78 (0.53 to 1.15)	0.204		
Number of surfaces restored (ref.: 1 surface)				
2 surfaces	1.92 (1.15 to 3.21)	0.012	1.96 (1.17 to 3.26)	0.010
3 or more surfaces	2.33 (1.42 to 3.82)	0.001	2.12 (1.30 to 3.49)	0.003
Dental material (ref.: composite resin)				
Glass-ionomer cement	1.02 (0.61 to 1.71)	0.947	0.91 (0.55 to 1.50)	0.702
Amalgam	0.55 (0.14 to 2.22)	0.405	0.64 (0.16 to 2.50)	0.518
Variables related to the clinical evaluation (1st level)				
Diagnostic method (ref.: CARS)				
FDI system	3.13 (2.08 to 4.73)	<0.001	3.14 (2.08 to 4.74)	<0.001
Order of examinations (ref.: 1st examination)				
2nd examination	1.03 (0.73 to 1.47)	0.857	1.08 (0.74 to 1.57)	0.686

* Variables not included in the final model

PR = prevalence ratio; 95%CI = 95% confidence intervals

dmf-t = decayed, missed and filled primary teeth; DMF-T = decayed, missed and filled permanent teeth

Source: The author

Table 4 - Association among explanatory variables and any type of treatment for the restoration (outcome) decided by two different criteria system: International Dental Federation criteria (FDI) and using Caries Around Restorations System (CARS)

Explanatory variables	**Unadjusted PR (95%CI)**	**p**	**Adjusted PR (95%CI)**	**P**
Variables related to the children (3rd level)				
Sex (ref.: male)			*	
Female	0.82 (0.65 to 1.03)	0.091		
Age (ref.: 3 to 6 yrs-old)			*	
7 to 10 yrs-old	0.96 (0.76 to 1.21)	0.748		
Number of restorations (ref.: 1 to 3 restorations)			*	
More than 3 restorations	0.99 (0.76 to 1.29)	0.940		
Number of decayed teeth (quant.)	1.12 (1.05 to 1.19)	<0.001	1.08 (1.02 to 1.14)	0.006
Number of filled teeth (quant.)	1.00 (0.95 to 1.04)	0.911	*	
Number of missed teeth (quant.)	0.92 (0.81 to 1.05)	0.203	*	
dmf-t + DMF-T	1.03 (0.99 to 1.06)	0.158	*	
Variables related to the restored tooth (2nd level)				
Dental arch (ref.: upper)			*	
Lower	1.01 (0.84 to 1.23)	0.879		
Number of surfaces restored (ref.: 1 surface)				
2 surfaces	1.96 (1.52 to 2.52)	<0.001	1.93 (1.50 to 2.49)	<0.001
3 or more surfaces	2.64 (2.08 to 3.35)	<0.001	2.49 (1.96 to 3.18)	<0.001
Dental material (ref.: composite resin)				
Glass-ionomer cement	1.23 (0.95 to 1.59)	0.125	1.13 (0.88 to 1.44)	0.330
Amalgam	0.90 (0.47 to 1.70)	0.740	1.04 (0.56 to 1.94)	0.892
Variables related to the clinical evaluation (1st level)				
Diagnostic method (ref.: CARS)				
FDI system	1.16 (0.97 to 1.39)	0.099	1.16 (0.97 to 1.39)	0.099
Order of examinations (ref.: 1st examination)				
2nd examination	1.00 (0.84 to 1.20)	1.000	1.01 (0.84 to 1.20)	0.951

* Variables not included in the final model

PR = prevalence ratio; 95%CI = 95% confidence intervals

dmf-t = decayed, missed and filled primary teeth; DMF-T = decayed, missed and filled permanent teeth

Source: The author

Table 5 - Association among explanatory variables and presence of caries lesions (outcome) detected by two different criteria system: International Dental Federation criteria (FDI) and using Caries Around Restorations System (CARS)

Explanatory variables	Unadjusted PR (95%CI)	p	Adjusted PR (95%CI)	p
Variables related to the children (3rd level)				
Sex (ref.: male)			*	
Female	0.86 (0.66 to 1.13)	0.271		
Age (ref.: 3 to 6 yrs-old)			*	
7 to 10 yrs-old	0.91 (0.70 to 1.19)	0.506		
Number of restorations (ref.: 1 to 3 restorations)			*	
More than 3 restorations	1.01 (0.74 to 1.38)	0.952		
Number of decayed teeth (quant.)	1.15 (1.07 to 1.23)	<0.001	1.11 (1.04 to 1.19)	0.002
Number of filled teeth (quant.)	1.00 (0.95 to 1.06)	0.904	*	
Number of missed teeth (quant.)	0.89 (0.76 to 1.03)	0.130	*	
dmf-t + DMF-T	1.04 (0.99 to 1.08)	0.087	*	
Variables related to the restored tooth (2nd level)				
Dental arch (ref.: upper)				
Lower	0.93 (0.75 to 1.15)	0.502	*	
Number of surfaces restored (ref.: 1 surface)				
2 surfaces	1.78 (1.32 to 2.39)	<0.001	1.76 (1.31 to 2.37)	<0.001
3 or more surfaces	2.47 (1.87 to 3.25)	<0.001	2.29 (1.73 to 3.02)	<0.001
Dental material (ref.: composite resin)				
Glass-ionomer cement	1.19 (0.89 to 1.61)	0.247	1.09 (0.82 to 1.45)	0.563
Amalgam	0.69 (0.31 to 1.53)	0.364	0.81 (0.37 to 1.78)	0.604
Variables related to the clinical evaluation (1st level)				
Diagnostic method (ref.: CARS)				
FDI system	1.47 (1.19 to 1.81)	0.001	1.46 (1.18 to 1.81)	<0.001
Order of examinations (ref.: 1st examination)				
2nd examination	0.97 (0.79 to 1.20)	0.791	0.99 (0.80 to 1.22)	0.899

* Variables not included in the final model

PR = prevalence ratio; 95%CI = 95% confidence intervals

dmf-t = decayed, missed and filled primary teeth; DMF-T = decayed, missed and filled permanent teeth

Source: The author

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APPENDIX A - Table 1. International Dental Federation (FDI) criteria linked to the treatment decision

FDI scores					FDI treatment
Scores	**Classification**	**Marginal staining***	**Marginal adaptation**	**Recurrence of caries**	**Indication**
1	**Clinically excellent/ very good**	No marginal staining.	Harmonious outline, no gaps, no white or discolored lines	No secondary or primary caries	No treatment
2	**Clinically good**	Minor marginal staining, easily removable by polishing.	Marginal gap (<150 µm), white lines. Small marginal fracture removable by polishing. Slight ditching, slight step/flashes, minor irregularities. Gap < 250µm not removable.	Very small and localized demineralization	No treatment
3	**Clinically sufficient/ satisfactory**	Moderate marginal staining, not esthetically unacceptable.	Several small marginal fractures. Major irregularities, ditching or flash, steps. Gap > 250µm or dentine/base exposed.	Larger areas of demineralisation	No treatment
4	**Clinically unsatisfactory**	Pronounced marginal staining; major intervention necessary for improvement.	Severe ditching or marginal fractures. Larger irregularities or steps.	Caries with cavitation	Repair
5	**Clinically poor**	Deep marginal staining, not accessible for intervention.	Restoration (complete or partial) is loose but in situ. Generalized major gaps or irregularities.	Deep secondary caries or exposed dentine that is not accessible for repair of restoration.	Replacement

Source: The author

APPENDIX B - Table 2. Caries Associated with Restorations and Sealants (CARS) Criteria

Caries Associated with Restorations and Sealants codes		
Code 0	**Sound tooth surface with restoration or sealant**	A sound tooth surface adjacent to a restoration/sealant margin. There should be no evidence of caries (either no or questionable change in enamel translucency after prolonged air drying for 5 seconds). Surfaces with marginal defects less than 0.5mm in width (i.e. will not admit the ball end of the CPI Probe), developmental defects such as enamel hypoplasias; fluorosis; tooth wear (attrition, abrasion and erosion), and extrinsic or intrinsic stains will be recorded as sound. Stained margins consistent with non-carious habits (e.g. frequent tea drinking) and which do not exhibit signs consistent with demineralization should be scored as sound.
Code 1	**First visual change in enamel**	When seen wet there is no evidence of any change in colour attributable to carious activity, but after prolonged air drying (for approximately 5 seconds) an opacity or discolouration consistent with demineralization is visible that is not consistent with the clinical appearance of sound enamel.
Code 2	**Distinct visual change in enamel/dentin adjacent to a restoration margin**	If the restoration margin is placed on enamel the tooth must be viewed wet. When wet there is an opacity consistent with demineralization or discolouration that is not consistent with the clinical appearance of sound enamel (Note: the lesion is still visible when dry). If the restoration margin is placed on dentin: Code 2 applies to discoloration that is not consistent with the clinical appearance of sound dentin or cementum.
Code 3	**Carious defects of <0.5 mm with the signs of code 2**	Cavitation at the margin of the restoration/sealant less than 0.5mm, in addition to either an opacity or discolouration consistent with demineralization that is not consistent with the clinical appearance of sound enamel or with a shadow of discoloured dentin.
Code 4	**Marginal caries in enamel/dentin /cementum adjacent to restoration with underlying dark shadow from dentin**	The tooth surface may have characteristics of code 2 and has a shadow of discoloured dentin which is visible through an apparently intact enamel surface or with localized breakdown in enamel but no visible dentin. This appearance is often seen more easily when the tooth is wet and is a darkening and intrinsic shadow which may be grey, blue, orange, or brown in colour. Note: view tooth wet and then dry. This lesion should be distinguished from amalgam shadows.
Code 5	**Distinct cavity adjacent to restoration**	Distinct cavity adjacent to restoration/sealant with visible dentin in the interfacial space with signs of caries as described in code 4, in addition to a gap > 0.5mm in width. OR In those instances where margins are not visible, there is evidence of discontinuity at the margin of the restoration/sealant and tooth substance of the dentin as detected by 0.5mm ball-ended probe run along the restoration/sealant margin.
Code 6	**Extensive distinct cavity with visible dentin**	Obvious loss of tooth structure, the extensive cavity may be deep or wide and dentin is clearly visible on both the walls and at the base.

Source: The author

APPENDIX C - Table 3. Characteristics of Active and Inactive Caries Linked to Caries Around Restorations System - CARS adapted

ICCMS Code	Characteristics of Lesion	
	Signs of Active Lesions	Signs of Inactive Lesions
ICCMS Initial and Moderate Caries Stage	Surface of enamel is whitish/yellowish; opaque with loss of luster, feels rough when the tip of the ball-ended probe is moved gently across the surface. Lesion is in a plaque stagnation area, i.e. in the entrance of pits and fissures, near the gingival margin or, for proximal surfaces, below or above the contact point. The lesion may be covered by thick plaque prior to cleaning	Surface of enamel is whitish, brownish or black. Enamel may be shiny and feels hard and smooth when the tip of the ball-ended probe is moved gently across the surface. For smooth surfaces, the caries lesion is typically located at some distance from the gingival margin. Lesion may not be covered by thick plaque prior to cleaning
ICCMS Extensive Caries Stage	Dentine feels soft or leathery on gentle probing	Dentine is shiny and hard on gentle probing

Source: The author

APPENDIX D - Table 4. Treatment decision linked to the Caries Associated with Restoration and Sealants (CARS) criteria – Adapted

0	**No treatment**	No treatment	**-**
1	**Non-operative treatment**	No treatment [1] Topical fluoride application [2]	[1] Adjacent inactive lesion [2] Adjacent active lesion.
2		No treatment [1] Topical fluoride application [2]	
3		No treatment [1] Topical fluoride application [2]	
4	**Operative treatment**	Repair Replacement[3]	[3] Replacement should be indicated in case the carious lesion involves more than half of the restoration.
5		Repair Replacement[3]	
6		Repair Replacement[3]	

Source: The author

5 CHAPTER III: DIAGNOSTIC ACCURACY STUDY

Clinical performance of two different criteria for the detection of caries lesions around restorations in primary teeth

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Short Title: Clinical diagnosis of secondary caries lesions in primary teeth.

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Abstract

Objectives: This is a delayed type cross-sectional prospective accuracy study nested in a randomized clinical trial. This study aimed to investigate the diagnostic accuracy of two visual criteria for caries lesions detection around restorations in primary teeth: the criteria proposed by the International Dental Federation (FDI) and the Caries Associated with Restorations and Sealants (CARS) system. **Methods:** A trained and calibrated examiner evaluated restorations in children (three to 10 years old). Initially, the visual assessment was performed according to the participant's allocation group (FDI or CARS system) considering the main clinical trial. For FDI system, three parameters were considered: presence of caries, marginal adaptation and marginal staining. After reaching the diagnosis and treatment decision, the same examiner performed a second evaluation according to the other criteria. The reference standard methods were the restoration removal and visual-tactile examination of dentin beneath the margin interface when the replacement was indicated or visual-tactile detection and assessment of the restoration after six and 12 months of follow-up. The scores obtained with the CARS and FDI criteria were dichotomized according to cut-offs predetermined considering the dentin caries threshold. Sensitivity, specificity, and accuracy parameters were calculated considering both visual criteria and the reference standard results. Poisson multilevel regression analyses were performed to evaluate the association of the diagnostic methods and other explanatory variables with three outcomes: sensitivity, specificity, and accuracy. Prevalence ratios (PR) and respective 95% confidence intervals (95%CI) were calculated. **Results:** Of the 651 restorations included in this study, 480 were evaluated by reference standard methods and included in the analyses. The CARS system presented higher accuracy (0.721) than those obtained with FDI recurrence of caries, FDI marginal adaptation and FDI marginal staining (varying from 0.681 to 0.702). The FDI marginal staining showed the lowest sensitivity (0.280) and accuracy (0.681) values of the study. The specificity values of FDI recurrence of caries (PR= 0.98; 95%CI 0.95-0.99) and FDI marginal adaptation (PR= 0.95; 95%CI 0.91-0.99) were lower than the CARS system. The diagnosis of caries around multisurface restorations was overestimated compared to single surface restorations. Restorations assessed after the follow-up period presented lower sensitivity but higher specificity than those replaced after initial evaluation. **Conclusion:** The CARS

system is the most accurate diagnostic method to detect caries around restorations in primary teeth. However, the FDI recurrence of caries and FDI marginal adaptation present similar performance to the CARS system when the dentin threshold is considered. On the other hand, marginal staining is not an accurate parameter to evaluate secondary caries.

5.1 Introduction

Experts in restorative and preventive dentistry have reached a consensus that the prevention of caries around restorations is one of the highest important issues over the next 20 years (1). This is why caries is considered one of the major reasons for restoration failure (2,3). The subsequent interventions, such as the replacement, invariably result in removing healthy dental tissue and weakening the remaining structure, accelerating the restorative death spiral (4). Although the term “secondary caries” is frequently used, the disease's pathogenesis is the same involving demineralization as any caries lesion but is modified by the presence of a restoration or a sealant margin (5). Thus, no discrimination is made in this study between the terms secondary caries lesion, lesions adjacent to restoration and caries lesion around restoration.

Increasing efforts are made to improve restorative materials' properties to prevent secondary caries development based on the frequency of reinterventions and costs generated because of these lesions (6,7). However, an accurate diagnosis of caries lesions around restorations is often challenging for dentists due to confounding factors such as gaps between the restoration and tooth surface and marginal staining (8). One of the predominantly areas where secondary caries lesions are located is at gingival margins of interproximal areas, which are difficult to assess because it is impossible to view them directly and the dental probe tends to stick even into caries-free marginal gaps or overhangs (8,9). An additional factor is that there is no standard criterion to be used when performing the secondary caries lesion detection, and there is a heterogeneity of subsequent treatment decisions (10). The criteria on which restoration replacement are based have limited accuracy, which can potentially lead to false-positive diagnoses and unnecessary reinterventions in permanent teeth (11). The scenario is even worse when it comes to primary teeth. A systematic review about the accuracy of various detection methods of secondary

caries included two studies under clinical conditions and only two in vitro studies assessed restorations in primary teeth (10).

Detailed visual systems have been proposed to improve the accuracy and reliability of visual inspection for caries around restorations. Among the available criteria, the International Caries Classification and Management System (ICCMS) includes a list of well-described criteria for Caries Associated with Restorations and Sealants (CARS) (12,13). There is robust evidence to support and encourage the use of the International Caries Detection and Assessment System (ICDAS) proposed by the ICCMS when assessing primary coronal caries lesions (14). However, as far as the authors know, no previous investigation has evaluated the CARS system's accuracy in detecting caries lesions around restorations in primary teeth in a clinical setting. On the other hand, the clinical criteria approved by the FDI World Dental Federation (FDI criteria) for evaluating restorations have already been used by several investigators (15). It has been considered a “standard criteria” when restorative materials or operative techniques are clinically investigated (15). The criteria system presents sixteen clinical criteria available for evaluation, being one of those the “recurrence of caries”. Furthermore, other subcategories of the FDI criteria that many dentists and studies have associated with caries lesion around the restoration are marginal staining and defects on marginal adaptation (16)., are also of evaluation from the FDI criteria.

Nevertheless, to the present moment, no study has compared the performance of the FDI criteria and the CARS system clinically in detecting caries lesions around restorations in primary teeth. Therefore, the present study aimed to investigate the accuracy of these two methods for caries lesions detection around restorations in primary teeth. The working hypothesis is that the CARS system is more accurate than the FDI criteria when detecting caries lesions adjacent to restorations in primary teeth since the method is more focused on the diagnosis of caries lesions. A secondary aim was to evaluate the effect of different reference tests used for the validation of the diagnostic strategies, as well as the association of other independent variables, on the accuracy parameters obtained with the methods.

5.2 Materials and Methods

Study design and ethical aspects

This is a delayed type cross-sectional prospective study designed to investigate the accuracy of two visual methods for caries lesion detection around restorations in primary teeth. The manuscript was written according to the “Standards for Reporting Diagnostic Accuracy Studies” (STARD) guideline. The STARD checklist is presented in Appendix A in Online Supplementary Material. The local committee for ethics in research approved this study. Patients were included in the study after their legal guardians signed the informed consent form and literate children signed an assent form.

The present study is nested in a randomized clinical trial that aims to evaluate the effect of using two visual criteria to assess caries lesions around restorations in primary teeth on outcomes related to oral health in children after two-years of follow-up. The main clinical trial, named Caries Detection in Children nº 3 (CARDEC-3), is registered at the platform Clinicaltrials.gov (NCT03520309). The CARDEC-3 protocol is published elsewhere and contains more information about the clinical trial (17).

Participants selection

Participants aged three to 10 years old were randomly selected from a list of patients who sought dental treatment in the School of Dentistry of the University of São Paulo from November 2017 to November 2018 until the required sample size was reached. Therefore, the study setting was the dental office.

The inclusion criteria were children: (1) whose parents sought dental treatment at the School of Dentistry of the University of São Paulo; (2) from three to 10 years old; and (3) presenting at least one restoration of any kind of restorative material (composite resin, amalgam or glass ionomer cement) on a primary tooth (anterior or posterior) regardless of its condition. The exclusion criteria were children: (1) whose parents did not agree to participate in the study; (2) who did not agree to participate or showed behavior problems during the first appointment. All children’s restorations were evaluated, except restorations on teeth with fistula, abscess, pulp exposure, history of spontaneous dental pain or mobility. Children presenting these conditions

in one or more teeth and presenting at least one eligible tooth fitting the inclusion criteria were included in the study.

Dietary advice and oral hygiene instructions were delivered during the first dental appointment for all children and their parents or legal guardians. The correct use of toothbrush and toothpaste (1000–1500 ppm of fluoride) was demonstrated and prescribed. Participants also underwent professional dental cleaning with bristle rotating brush, pumice, water slurry, and dental floss before restorations were evaluated.

Caries lesion detection methods

All the clinical examinations were conducted with participants seated on a dental chair after cleaning procedures and under artificial light. Initially, participants underwent a visual inspection performed by an independent examiner (LRAP) to assess children's caries experience and additional dental treatment needs, not related to the restorations included in the study. Visual inspection was performed according to ICDAS (12,13) to detect coronal primary caries lesions and their activity status (12,13). A plane buccal mirror, a ball-ended dental probe and cotton wool rolls were used for all visual and tactile examinations conducted in this study.

Following the initial examination, a previously trained and calibrated examiner (BLPM) performed the evaluations in all included restorations. This examiner reached intra-examiner and inter-examiner weighted kappa value greater than 0.75 for both FDI and CARS criteria previously to begin the study. Detailed information regarding the examiner training and calibration can be assessed in the clinical trial study protocol (17). Restorations were first evaluated according to the participant's allocation group considering the clinical trial. After reaching the diagnosis and treatment decision, the same examiner (BLPM) performed a second evaluation according to the other criteria. This procedure did not influence the classification and treatment decision proposed by the first criteria to which the participant was allocated.

The two diagnostic methods used for the restoration’s evaluations were:

- FDI: diagnosis and treatment decision based on the International Dental Federation (FDI) criteria (15).

• CARS: diagnosis according to the Caries Associated with Restorations or Sealants (CARS) system, proposed by the ICCMS (12) and updated in the CariesCare International 4D (13). The treatment decision was based on the recommendations described in guidelines (12, 13) to treat coronal primary caries lesions.

For the evaluations performed with the FDI criteria, all surfaces were dried before the examination. The restorations assessed according to the CARS system were first evaluated wet and then dried for five seconds with a triple syringe according to the ICCMS (12) and CariesCare 4D (13) recommendations.

The FDI criteria are categorized into three different parameters of evaluation: esthetic (four criteria), functional (six criteria), and biological (six criteria). Each criterion within these parameters is expressed with five scores, three for restoration acceptable and two for non-acceptable (one for repair as treatment decision and one for restoration replacement). The final restoration score is the highest score obtained among all criteria. It has been advised that researchers should select the most suitable criteria to use according to their studies among all subcategories (20,16). For this reason, we selected three FDI criteria to be used in our clinical evaluations: marginal staining, marginal adaptation, and recurrence of caries.

Regarding the CARS criteria, the same stages for coronal primary caries lesions from ICDAS (12,13) are used to detect caries lesion adjacent to restoration or sealant. The activity status described in the CariesCare 4D (13) to assess caries lesions' activity status was also used in association with the CARS criteria in this study. The system does not have a detailed treatment decision linked to the CARS scores. The authors adapted the recommendations described in the ICCMS (12) and in the CariesCare 4D (13) for the treatment of primary caries to use in this study. A detailed description of the FDI and the CARS system used in this study can be assessed in the clinical trial study protocol (17).

The treatment decisions for all restorations evaluated according to the FDI or CARS criteria were classified into no treatment and restoration follow-up; professional topical fluoride application; restoration refurbishment; and restoration repair or replacement. This study considered only data regarding the restoration replacement (complete removal of the restoration present on the tooth) (18).

Reference standard methods

The reference standard for visual methods' validation was composed by two different approaches. First method was the restoration removal and tactile examination of dentin beneath the margin interface (detectable softening of the dentin) when the FDI or CARS system indicated the restoration replacement. The presence or absence of soft or hard carious tissue was evaluated and recorded by two independent operators (H.C.M.M. and R.D.F.), who are postgraduate dental students in Pediatric Dentistry responsible for providing dental treatment needs for the children. They were trained and calibrated before the beginning of the study, and the assessment started after the intra-examiner and inter-examiner weighted kappa values reached values greater than 0.75 for both.

The restorative material was removed carefully using a tungsten carbide bur in a high-speed handpiece under water refrigeration for the restoration replacement. Any contact with the cavity walls and margins was avoided. The remnants of restorative material in the cavity were removed using a sharp excavator. After removing the restoration, the caries lesion detection was performed with the visual inspection with a ball-ended dental probe. The presence of soft dentin or leathery on gentle probing was classified as decayed by the reference standard. If the dentin was shiny and hard on gentle probing, it was classified as sound by the reference standard. The results of the reference standard were collected using a specific sheet by the operators of the study. This reference standard was selected to be used because it follows the treatment decisions in clinical practice. The operators were unaware of which diagnostic method (FDI or CARS system) was used to reach the decision to replace the restoration. A treatment plan carried out by the examiner responsible for restorations' initial examination (B.L.P.M.) was provided, indicating only which dental treatment they should perform in the evaluated restorations.

For the validation of the restorations that were not indicated to be replaced in the baseline assessments, we followed-up the children and reassessed the restorations after six and 12 months by another independent and experienced examiner (T.K.T.). This reference standard method corresponds to a visual-tactile detection and assessment of the restoration. The absence of signs of caries and changes in enamel seen as a carious around restoration after these follow-ups were classified as sound by the reference standard. If a cavity extending into dentine around the

restoration with the presence of soft dentin or leathery on gentle probing was detected, it was classified as decayed by the reference standard. On the other hand, if a cavity extending into dentine was shiny and hard on gentle probing, it was classified as sound by the reference standard. The examiner was blind to the evaluations performed with the FDI and CARS system.

Although there was a follow-up period for the diagnostic assessment of restorations classified as without the need for replacement in the study's baseline, this is still considered a cross-sectional study. It is known in the literature as a "delayed type" cross-sectional study (19) and has already been used previously on caries diagnostic research (20). This reference standard was the most acceptable solution to be adopted since, for ethical reasons, we could not perform an invasive dental treatment as the replacement in all restorations evaluated in this study.

Sample size calculation and statistical analysis

The sample size calculation was based on the primary outcome of the randomized clinical trial (17), which was the percentage of restorations requiring reintervention. For the main clinical trial, the minimum sample size was 626 restored primary teeth. For the present accuracy study, all restorations were included. A post-hoc calculation of the power achieved in the comparisons between the methods was made.

Descriptive analysis considering the characteristics of the restorations included in the study was presented. Moreover, a cross-tabulation of the results obtained with different diagnostic strategies for caries around restorations by the reference standard results was made.

The scores obtained with the CARS and FDI method (considering the parameters dental caries, marginal adaptation and staining) were dichotomized according to cut-offs predetermined considering the plausibility, only at the dentin caries threshold. Therefore, restorations were classified with dentin dental caries when the scores were higher than 4 considering the CARS method, and higher than 3 for the FDI parameters. After dichotomization, sensitivity, specificity and accuracy parameters were calculated considering as reference standard the results obtained with operative treatment performed at the baseline or obtained with the assessment after one year of follow-up. Accuracy refers to the percentage of correct diagnosis,

independently of the tooth condition (sound or decayed). The restorations that were not evaluated by the reference standard methods were excluded of the analysis. The 95% Confidence intervals (95% CI) were calculated considering the cluster nature of the sample, since many participants had more than one restoration included in the study. Differences between the methods were assessed by McNemar test.

After that, multilevel Poisson regression analysis with robust variance was conducted to evaluate the association of the diagnostic methods and other explanatory variables with three outcomes: sensitivity (false negative results vs. true positive results); specificity (false positive vs. true negative) and accuracy (false results vs. true results). Some explanatory variables tested were related to the participant, such as age group (3 to 6 years old vs. 6 to 10 years old), caries experience (quantitative variable derived from the number of decayed, missed and filled primary – dmft and permanent teeth – DMFT). Other variables were related to the restored tooth, such as type of teeth (posterior vs. anterior), dental arch (upper vs. lower), restorative material (glass ionomer cement as reference, composite, amalgam), number of surfaces restored (1 surface, 2 surfaces, 3 or more surfaces restored), diagnostic method (CARS method as reference, FDI caries, FDI Adaptation and FDI staining) and reference standard method (evaluation after restoration replacement at the baseline vs. assessment after the follow-up). With this approach, prevalence ratio (PR) values and respective 95% CI were derived.

First, univariate analyses were performed. After that, multiple models were built including the diagnostic methods and explanatory variables that presented p value lower than 5%. The analyses were performed using the statistical package Stata 15.0 (StataCorp LLC, College Station, USA). The level of significance for all analysis was set at 5%.

5.3 Results

Of the 163 children who were invited, 88 (54.0%) were boys, and 77 (47.2) were 3 to 6 years old. The mean (Standard Deviation - SD) age of the sample was 7.0 (1.6) years. The mean (SD) of number of decayed, missed or filled primary or permanent teeth (dmf-t + DMF-T) was 6.6 (3.6), with a range of 1 to 16. The number of restored teeth presented a mean (SD) of 4.6 (2.6), varying from 1 to 12

restorations. Characteristics of all restorations initially included in the study are presented in the table 1.

Considering all children, we could assess the restorations in only 124 children (76.1%). The reasons for the impossibility of assessment were because the children did not return after 1 year (7 children), included teeth are with complete loss of restoration (6 children), or the included teeth had been extracted (in 6 children) or exfoliated (in 20 children). Therefore, these 124 children contributed with 480 restorations, that were analyzed in the present study. The characteristics of children and their restorations that were analyzed are also presented at the table 1. Reasons for the drop-out were also reported (Table 1).

Slight imbalances could be observed in the type of teeth and number of surfaces restored. First condition was probably impacted by exfoliation of the teeth, since a lower proportion of anterior teeth was assessed after the follow-up. Differences between number of surfaces restored, on the other hand, probably was due to the missed restorations and extracted teeth after the follow-up. All participants were submitted to both FDI and CARS diagnostic strategies for the evaluation of restorations. In 244 restorations included (50.8%) CARS was first performed, while in 236 restorations (49.2%), the first evaluation method was the FDI.

The results obtained with the reference standard strategy (sound or decayed) were divided into “assessed after restoration replacement at the baseline” and “assessment after one year follow-up”. Sixty-three restorations were replaced after the visual assessment performed in the beginning of the of the study, and 417 restorations were visually assessed after six months and one year (Table 2). The number of sound teeth was much higher for the those assessed after the follow-up period (n = 329) compared with the replaced restorations (n = 9) (Table 2). The prevalence of caries around the restorations observed in the study was 29.6% (Table 2) and the distribution of the scores of the CARS system and FDI criteria are also presented in Table 2.

Concerning the accuracy parameters obtained with the diagnostic methods for detecting dentin caries lesions around restorations, the specificity and accuracy values of the CARS system were similar to the FDI recurrence of caries (Table 3). The FDI marginal adaptation presented significantly lower specificity than the CARS system (Table 3). The FDI marginal staining reached the lowest sensitivity and accuracy values than the other evaluation parameters (Table 3). Nevertheless, the

FDI marginal staining presented the highest specificity value than the CARS system and other considered FDI parameters (Table 3). Witch the values obtained with the CARS method and our sample size, we calculated a power of 0.68, 0.98 and 0.99 to find a difference of at least 0.15 between the methods considering a 5% level of significance.

The univariate multilevel Poisson regression analysis of the different methods for detecting caries lesions around restorations and other explanatory variables and accuracy parameters showed that the specificity values of the FDI recurrence of caries and marginal adaptation were significantly lower to the CARS system (Table 4). The FDI recurrence of caries also presented a lower accuracy value than the CARS system (Table 4). However, the FDI marginal staining showed a much lower sensitivity value than the CARS system (Table 4). On the other hand, the FDI marginal staining specificity was significantly higher than the CARS system (Table 4).

Regarding the restorative materials, the univariate analysis showed that the detection of caries around restorations was more accurate for composite restorations than glass-ionomer cement restorations (Table 4). The number of restored surfaces also influenced the performance of the methods. The detection of secondary caries in restorations with three or more surfaces presented higher sensitivity and lower specificity than single surface restorations, independently of the diagnostic method used for the assessment (Table 4). The accuracy of the methods for detecting caries around multisurface restorations was lower than single surface restorations leading to a possible overdiagnosis (Table 4). The specificity value of two surface restorations was also lower than single surface restorations. Besides that, the analysis showed that the performance of the methods for detecting secondary caries in restorations validated with the assessment after one year of follow-up showed significantly lower sensitivity, higher specificity, and higher accuracy than those replaced at the beginning of the study (Table 4).

The multiple multilevel Poisson regression analysis among the different methods for detecting caries lesions showed that the PR for the three considered outcomes of the study (sensitivity, specificity, and accuracy) presented similar values and the same trends observed in the the univariate analysis (Table 5). The FDI recurrence of caries showed lower specificity and accuracy values than the CARS system in detecting caries around restorations in primary teeth (Table 5). Similarly, the FDI marginal adaptation presented lower specificity value than the CARS system (Table

5). The FDI marginal staining still showed a much lower sensitivity value than the CARS system but higher specificity in detecting secondary caries in primary teeth (Table 5).

Similar results were obtained regarding the higher accuracy of the methods in detecting caries around composite restorations than glass-ionomer cement restorations (Table 5). It was also obtained higher sensitivity and lower specificity in detecting caries around restorations with three or more surfaces than single surface restorations, resulting in lower accuracy value (Table 5). The detection of caries around two surface restorations also showed a lower specificity value than single surface restorations (Table 5). In the same way, restorations assessed after the follow-up period presented lower sensitivity but higher specificity than those replaced at the beginning of the study. More interestingly is that the presence of this variable in the multiple analysis did not change the tendencies when the performance of the diagnostic methods was compared (Table 5).

5.4 Discussion

Only a few studies investigated the detection of caries lesion around restorations, most of them with a high risk of bias and applicability concerns (10). The visual examination aided by a tactile instrument is still one of the most common methods used for secondary caries lesion detection (21,22). It has already been shown that the use of detailed and validated indices seems to improve the accuracy of the visual method for detecting primary carious lesions (23). However, standardization criteria are absent for assessing secondary caries, which is probably associated with excessive and unnecessary interventions on restorations (16). Thus, the present study investigated the accuracy of two visual criteria, the FDI and the CARS system, to detect caries around restorations in primary teeth.

The current study found that the CARS system and FDI for recurrence of caries perform similarly in detecting dentin caries lesions around restorations. This result may be explained by the fact that even though the CARS system comprises seven scores and the FDI recurrence of caries shall consist of five codes, the diagnosis of lesion's severity is described similarly in both criteria. The CARS was considered a more suitable system since it also describes other aspects such as stained margins and amalgam shadows not consistent with caries lesions (16). The CARS system

also provides more detailed information about each stage of the caries process than the FDI recurrence of caries. There is no corresponding score of evaluation in the FDI criteria for marginal caries adjacent to restoration with underlying dark shadow from dentin (corresponding to CARS code 4). Nevertheless, the prevalence of such lesions was very low in this study.

Some aspects should be considered when using the CARS system to evaluate restorations. The system cannot distinguish between secondary caries and residual caries, and it should be used associated with a system for assessing lesion activity. Also, there is no defined treatment decision linked to the CARS classification to be used in clinical practice. The system cannot distinguish the recurrence of caries between other possible reasons for restoration failure, such as the presence of gap bulk fracture or restoration loss. On the other hand, the FDI criteria are originally applied when investigating restorative materials and operative techniques, but not only for caries lesion detection. In the present study, the FDI marginal adaptation presented similar specificity values and accuracy to the CARS system for detecting caries around restorations, although this parameter has reached lower figures. The evidence of the influence of marginal integrity and gap width on secondary caries development is inconclusive (24). Still, a possible explanation for the similar performance between them is because the cut-off predetermined in this study was at the dentin caries threshold. Thus, most frankly carious lesion at the filling margin also represents a gap with dentin exposure. At least at this threshold, marginal adaptation could be a surrogate for the presence of caries.

In contrast, the FDI marginal staining reached the lowest performance, indicating that staining around the restoration is not an accurate parameter for the detection presence of secondary caries. These results corroborate the findings of many previous studies (25–27). In most cases, the stain is associated with a margin defect, creating a gap between the tooth and the restorative material (28). Another possibility is regarding the presence of arrested caries. Dark areas around composite restorations could sign inactive residual caries left during selective removal of carious tissue that became arrested after the restoration's seal (29). The differential diagnosis of secondary carious lesions and residual lesions is challenging, and no diagnostic test has yet been able to precisely determine the lesions' origin (26). Therefore, it is recommended that clinicians should only intervene if signs of activity caries lesion are detected around restorations (29). For many years researchers are

stating that only frankly carious lesions at the filling margin constitute a reliable diagnosis of secondary caries (30).

Another relevant finding was the higher sensitivity and lower specificity in detecting caries around restorations with three or more surfaces than single surface restorations. These lower values also resulted in a lower accuracy in detecting secondary caries, independently of the diagnostic method used for the assessment. It is known that restorations in primary and permanent teeth with more than one surface involved present a higher risk of failure and are more likely to be replaced (31–33). This also accords with our earlier observations that multisurface restorations in primary teeth were more likely to have secondary caries lesion detected (31). The overdiagnosis observed in the current study regarding the detection of caries lesions around multisurface restorations may be explained by the anchoring heuristic occurrence (34). This phenomenon occurs when a single piece of information strongly influences a decision, particularly data encountered early in a given situation (35). Thus, in this study, the examiner probably anchors the clinical impressions upon features of a restoration's initial impression (more than one surface involved). Although the early emphasis on the number of restorations surfaces is appropriate, it generates bias due to undervaluation of later information regarding the caries lesion detection due to an initial anchor's potency.

The accuracy of detection methods is usually characterized by assessing their validity compared to a gold standard, which should be an independent assessment of the test performed, following a standardized protocol, and applied in all included objects (36). Nevertheless, there is no gold standard for assessing secondary caries lesions since there is a lack of clinical noninvasive reference standard methods (10). The restoration removal and tactile examination of dentin beneath the margin interface was possible to perform in the restorations indicated to be replaced by the visual methods. However, this reference standard was applied in only 63 included restorations in the study. To overcome this challenge, an alternative was planned to follow up the disease's clinical course during a suitable predefined period in a delayed-type cross-sectional study (19). This is probably the first diagnostic accuracy study of secondary caries lesion detection using this kind of reference standard.

After the follow-up period, it was observed that the number of sound teeth was much higher for the restorations assessed after one year of follow-up than the replaced ones. This finding was expected and may be explained by the fact that

when the diagnostic methods gave a positive result for secondary caries lesion in the first assessment of the study, operative treatment was performed. This also implies a lower sensitivity and higher specificity in the restorations that were validated with the assessment after the follow-up. However, using two different reference standard strategies could be considered a limitation of this study, since it has been observed that studies that used different reference standard methods have tended to overestimate the performance of these diagnostic tests (37).

On the other hand, it is interesting to note that in our study, the adjusted values of PR comparing the methods for three accuracy parameters were not significantly changed with the inclusion of this variable regarding the method of reference standard used. Thus, although it is not possible to evaluate if the use of different reference standard methods influenced the accuracy of the methods, this did not influence the comparison among the methods. This finding is interesting because strengthen the evidence obtained from studies where the use of a unique reference standard method is not possible, usually for ethical reasons.

It is known that there is a great need for studies about secondary caries detection, with an agreed reference standard and with robust internal and external validity to promote the translation into practice (10). Thus, the findings of this study are relevant, since the research was conducted on a sample of patients who sought dental treatment, which is the appropriate setting to investigate the utilization of diagnostic methods. Also, participants were randomly selected, and the researchers had no prior knowledge of their oral health conditions, reducing the risk of selection bias. The inclusion procedures were adopted to represent the main strength of the present diagnostic accuracy study.

The accuracy of a diagnostic method is an essential aspect to be evaluated. However, this type of study does not answer a fundamental question. For a diagnostic method to be considered useful, the study design should assess outcomes related to the patient's well-being. The research should also take the patient's perception into account. These data can only be evaluated in randomized clinical studies, as diagnostic accuracy studies do not deal with these evaluation aspects. Although the FDI recurrence of caries and FDI marginal adaptation presented similar performance to the CARS system in detecting secondary caries, evidence from a cross-sectional study shows that the FDI criteria suggest more invasive treatments than the CARS system for the treatment of posterior restorations

in primary teeth (31). Since several questions remain to be answered, future research should also evaluate the long-term impact of using these criteria in a randomized clinical study and not only the positive/negative test results for caries lesion detection. At the present moment, a clinical trial is being developed to reach this objective (17).

5.5 Conclusion

The CARS system is the most accurate diagnostic visual method to detect caries around restorations in primary teeth. However, the FDI criteria for evaluating recurrence of caries and marginal adaptation present similar performance to the CARS system when the dentin threshold is considered. On the other hand, marginal staining is not an accurate parameter to evaluate secondary caries and should not be used for this purpose in clinical practice.

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Statement of Ethics

The local ethics committee from the School of Dentistry of the University of São Paulo, São Paulo, Brazil, previously approved the study (registration no. 2.291.642) on 22 September 2017. This research is nested within a clinical trial, named Caries Detection in Children nº 3 (CARDEC-3), registered at Clinicaltrials.gov (NCT03520309).

Disclosure Statement

The authors declare that there are no conflicts of interest.

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Author Contributions

The researchers (F.M.M. and M.S.C.) conceived this study. The first author (B.L.P.M.) was responsible for overall study planning, restorations assessment, and article drafting. The researcher (L.R.A.P.) was responsible for initial examinations. The examiners (T.K.T., H.C.M.M. and R.D.F.) performed the assessment with the reference standard methods. The researcher (F.M.M.) was responsible for data analysis. All authors (B.L.P.M., L.R.A.P., T.K.T., H.C.M.M., R.D.F., D.P.R., M.M.B., K.R.E., J.C.P.I., M.S.C. and F.M.M.) contributed to data interpretation and final article draft.

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Table 1 - Characteristics of participants and restorations initially included and analyzed in the study (n = 651)

	Sample initially included	Sample analyzed
Explanatory variables	**N (%)**	**N %**
Characteristics of the Children		
Total	**163**	**124**
Sex		
Male	88 (54.0)	65 (52.4)
Female	75 (46.0)	59 (47.6)
Age (years old)		
Mean (Standard deviation)	7.0 (1.6)	6.9 (1.5)
dmf-t + DMF-T		
Mean (Standard deviation)	6.6 (3.6)	6.9 (3.5)
Number of restored teeth		
Mean (Standard deviation)	4.6 (2.6)	4.7 (2.6)
Characteristics of the restorations included		
Total	**651**	**480**
Type of tooth		
Posterior	561 (86.2)	427 (89.0)
Anterior	90 (13.8)	53 (11.0)
Dental arch		
Upper	311 (47.8)	225 (46.9)
Lower	340 (52.2)	255 (53.1)
Number of surfaces restored		
1 surface	270 (41.5)	215 (44.8)
2 surfaces	167 (25.7)	120 (25.0)
3 or more surfaces	214 (32.9)	145 (30.2)
Restorative material		
Glass-ionomer cement	442 (67.9)	332 (69.2)
Composite	189 (29.0)	137 (28.5)
Amalgam	20 (3.1)	11 (2.3)
Reference standard used		
Restoration replacement at the baseline		63 (9.7)
Assessment after 1 year of follow-up		417 (64.1)
Non-evaluated *		171 (26.3)
* Reasons for the non-evaluation		
Exfoliated		81 (12.4) **
Extracted or submitted to endodontic treatment		26 (4.0) **
Restoration missed		28 (4.3) **
Drop-out at 1 year of follow-up		36 (5.5) **
** frequencies calculated considering the 651 restorations initially included.		

Source: The author

Table 2 - Distribution of the scores according to the different methods for the detection of caries lesions around restorations and results obtained with the reference standard strategy

Diagnostic methods	Reference standard results				Total
	Sound		Decayed		
	Restoration replacement	Assessment after follow-up	Restoration replacement	Assessment after follow-up	
Total	9	329	54	88	480
Caries prevalence	338 (70.4%)		142 (29.6%)		
CARS scores					
0	1	153	5	26	185
1		3			3
2		37	1	5	43
3		55		10	65
4		3		1	4
5	4	61	11	33	109
6	4	17	37	13	71
FDI presence of caries					
1	1	153	7	26	187
2		63	1	11	75
3		29		6	35
4	3	70	11	33	117
5	5	14	35	12	66
FDI adaptation					
1		105	1	22	128
2		59	2	4	65
3		76	5	12	93
4	1	74	7	34	116
5	8	15	39	16	78
FDI staining					
1	8	226	39	59	332
2		65	5	21	91
3		24	7	7	38
4		11	1	1	13
5	1	3	2		6

CARS = Caries Detection around restorations system

FDI = World Dental Federation criteria

Source: The author

Table 3 - Accuracy parameters of diagnostic methods for the detection of caries lesions around restorations considering dentin caries lesions (n = 480)

Diagnostic methods	Cut-off point	Sensitivity	Specificity	Accuracy
		% (95% Confidence intervals)		
CARS scores	>4	66.2 [a] (57.6 to 73.8)	74.6 [b] (68.9 to 79.5)	72.1 [a] (67.6 to 76.2)
FDI presence of caries	>3	64.1 [a] (55.5 to 71.8)	72.8 [b, c] (66.8 to 78.1)	70.2 [b] (65.3 to 74.7)
FDI adaptation	>3	67.6 [a] (58.8 to 75.3)	71.1 [c] (64.7 to 76.6)	70.0 [a, b] (64.9 to 74.7)
FDI staining	>3	2.8 [b] (1.1 to 7.3)	95.6 [a] (0.92 to 97.6)	68.1 [a, b] (63.1 to 72.7)

CARS = Caries Detection around restorations system

FDI = World Dental Federation criteria

Different letters indicate statistically significant differences among the methods for the same accuracy parameters ($p < 0.05$, through McNemar test)

Source: The author

Table 4 - Univariate multilevel Poisson regression analysis among the different methods for the detection of caries lesions around restorations and other explanatory variables and parameters related to the accuracy (sensitivity, specificity and accuracy)

Explanatory variables	Sensitivity	p	Specificity	p	Accuracy	p
	Unadjusted PR (95% CI)		Unadjusted PR (95% CI)		Unadjusted PR (95% CI)	
Diagnostic methods (ref.: CARS)						
FDI caries	0.97 (0.92 to 1.01)	0.176	0.98 * (0.95 to 0.99)	0.032	0.97 * (0.95 to 0.99)	0.012
FDI adaptation	1.02 (0.96 to 1.09)	0.532	0.95 * (0.91 to 0.99)	0.028	0.97 (0.94 to 1.00)	0.078
FDI staining	0.04 * (0.02 to 0.11)	<0.001	1.28 * (1.20 to 1.37)	<0.001	0.95 (0.87 to 1.02)	0.160
Children' age (ref.: 3 to 6 yrs-old)						
7 to 10 yrs-old	1.12 (0.88 to 1.42)	0.375	1.04 (0.94 to 1.15)	0.424	1.05 (0.94 to 1.16)	0.390
dmft + DMFT (quantitative variable)	1.01 (0.97 to 1.05)	0.605	0.99 (0.98 to 1.01)	0.451	1.00 (0.98 to 1.01)	0.750
Tooth type (ref.: Posterior)						
Anterior	1.34 * (1.09 to 1.66)	0.005	1.01 (0.87 to 1.18)	0.885	1.12 (0.97 to 1.30)	0.125
Dental arch (ref.: upper)						
Lower	0.84 (0.67 to 1.04)	0.115	0.93 (0.85 to 1.02)	0.135	0.93 (0.85 to 1.02)	0.121
Restorative materials (ref.: Glass-ionomer cement)						
Composite	0.97 (0.72 to 1.31)	0.866	1.10 (0.99 to 1.22)	0.079	1.13 * (1.01 to 1.26)	0.029
Amalgam	0.99 (0.54 to 1.81)	0.978	1.18 (0.94 to 1.48)	0.157	1.11 (0.86 to 1.43)	0.412
Number of surfaces restored (ref.: 1)						
2 surfaces	1.38 (0.97 to 1.97)	0.069	0.88 * (0.79 to 0.98)	0.018	0.90 (0.81 to 1.00)	0.062
3 or more surfaces	1.41 * (1.01 to 1.96)	0.043	0.74 * (0.66 to 0.84)	<0.001	0.79 * (0.71 to 0.88)	<0.001
Reference standard method (ref.: Restoration replacement)						
Assessed after follow-up	0.61 * (0.49 to 0.75)	<0.001	2.88 * (1.86 to 4.45)	<0.001	1.17 * (1.04 to 1.33)	0.011

CARS = Caries Detection around restorations system

FDI = World Dental Federation criteria

PR = Prevalence ratio; 95% CI = 95% confidence interval

* association statistically significant ($p < 0.05$)

Source: The author

Table 5 - Multiple multilevel Poisson regression analysis among the different methods for the detection of caries lesions around restorations and other explanatory variables and parameters related to the accuracy (sensitivity, specificity and accuracy)

Explanatory variables	Sensitivity	p	Specificity	p	Accuracy	p
	Adjusted PR (95% CI)		Adjusted PR (95% CI)		Adjusted PR (95% CI)	
Diagnostic methods (ref.: CARS)						
FDI caries	0.97 (0.92 to 1.01)	0.176	0.98 * (0.95 to 0.99)	0.032	0.97 * (0.95 to 0.99)	0.012
FDI adaptation	1.02 (0.96 to 1.09)	0.532	0.95 * (0.91 to 0.99)	0.028	0.97 (0.94 to 1.00)	0.078
FDI staining	0.04 * (0.02 to 0.11)	<0.001	1.28 * (1.20 to 1.37)	<0.001	0.95 (0.87 to 1.02)	0.160
Tooth type (ref.: Posterior)						
Anterior	1.46 (0.91 to 2.33)	0.117	**		**	
Restorative materials (ref.: Glass-ionomer cement)	**		**			
Composite					1.11 * (1.01 to 1.23)	0.039
Amalgam					1.05 (0.82 to 1.35)	0.706
Number of surfaces restored (ref.: 1)						
2 surfaces	1.29 (0.92 to 1.80)	0.136	0.89 * (0.80 to 0.99)	0.034	0.93 (0.83 to 1.03)	0.164
3 or more surfaces	1.39 * (1.03 to 1.89)	0.043	0.76 * (0.67 to 0.85)	<0.001	0.80 * (0.72 to 0.89)	<0.001
Reference standard method (ref.: Restoration replacement)						
Assessed after follow-up	0.62 * (0.50 to 0.76)	<0.001	2.69 * (1.77 to 4.11)	<0.001	1.13 (0.99 to 1.29)	0.078

CARS = Caries Detection around restorations system

FDI = World Dental Federation criteria

PR = Prevalence ratio; 95% CI = 95% confidence interval

* association statistically significant ($p < 0.05$)

** variable was not included in the multiple model

Source: The author

APPENDIX A - Checklist of “Standards for Reporting Diagnostic accuracy studies” (STARD) guideline

Section & Topic	No	Item	Reported on page #
TITLE OR ABSTRACT			
	1	Identification as a study of diagnostic accuracy using at least one measure of accuracy (such as sensitivity, specificity, predictive values, or AUC)	2
ABSTRACT			
	2	Structured summary of study design, methods, results, and conclusions (for specific guidance, see STARD for Abstracts)	2
INTRODUCTION			
	3	Scientific and clinical background, including the intended use and clinical role of the index test	3 and 4
	4	Study objectives and hypotheses	4
METHODS			
Study design	**5**	Whether data collection was planned before the index test and reference standard were performed (prospective study) or after (retrospective study)	4
Participants	**6**	Eligibility criteria	5
	7	On what basis potentially eligible participants were identified (such as symptoms, results from previous tests, inclusion in registry)	4
	8	Where and when potentially eligible participants were identified (setting, location and dates)	4 and 5
	9	Whether participants formed a consecutive, random or convenience series	4
Test methods	**10a**	Index test, in sufficient detail to allow replication	6
	10b	Reference standard, in sufficient detail to allow replication	7 and 8
	11	Rationale for choosing the reference standard (if alternatives exist)	7 and 8
	12a	Definition of and rationale for test positivity cut-offs or result categories of the index test, distinguishing pre-specified from exploratory	8
	12b	Definition of and rationale for test positivity cut-offs or result categories of the reference standard, distinguishing pre-specified from exploratory	7 and 8
	13a	Whether clinical information and reference standard results were available to the performers/readers of the index test	7 and 8
	13b	Whether clinical information and index test results were available to the assessors of the reference standard	7 and 8
Analysis	**14**	Methods for estimating or comparing measures of diagnostic accuracy	8 and 9
	15	How indeterminate index test or reference standard results were handled	8 and 9
	16	How missing data on the index test and reference standard were handled	8
	17	Any analyses of variability in diagnostic accuracy, distinguishing pre-specified from exploratory	-
	18	Intended sample size and how it was determined	8
RESULTS			
Participants	**19**	Flow of participants, using a diagram	-
	20	Baseline demographic and clinical characteristics of participants	Page 9 and Table 1
	21a	Distribution of severity of disease in those with the target condition	Table 2
	21b	Distribution of alternative diagnoses in those without the target condition	-
	22	Time interval and any clinical interventions between index test and reference standard	7
Test results	**23**	Cross tabulation of the index test results (or their distribution) by the results of the reference standard	Table 2
	24	Estimates of diagnostic accuracy and their precision (such as 95% confidence	Table 3

		intervals)	
	25	Any adverse events from performing the index test or the reference standard	-
DISCUSSION			
	26	Study limitations, including sources of potential bias, statistical uncertainty, and generalisability	13 and 14
	27	Implications for practice, including the intended use and clinical role of the index test	11 to 15
OTHER INFORMATION			
	28	Registration number and name of registry	4
	29	Where the full study protocol can be accessed	4
	30	Sources of funding and other support; role of funders	15 and 16

6 CHAPTER IV: IN VITRO STUDY

In vitro performance of three-dimensional intraoral scanner and two visual criteria in detecting caries around composite restorations

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Short Title: The performance of three methods in detecting secondary caries and predict its severity

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Abstract

Objectives: To evaluate the in vitro performance in detecting caries and predict its severity around composite restorations in permanent posterior teeth of a three-dimensional (3D) intraoral scanner and two visual criteria: International Dental Federation (FDI) criteria and the Caries Associated with Restorations and Sealants (CARS) system. **Methods:** one hundred sixteen teeth were visually assessed by a trained and calibrated examiner according to the FDI criteria or CARS system. The order of the visual criteria used by the examiner was chosen randomly. Another examiner scanned the teeth using the 3D intraoral scanner. The gap was measured using specific software. The reference standard was the histological examination performed by an examiner blind to the other evaluations. Unweighted and weighted kappa tests were conducted to assess the intra-examiner reproducibility of the scoring system. Spearman's correlation coefficient (Rho) and 95% confidence intervals (95%CI) were calculated between the histological examination and scores obtained with the FDI criteria and the CARS system, as well as with respective treatment decisions. Spearman correlation between the visual and scanner evaluation with the reference standard was also performed. Spearman's rank correlation analyses were also conducted independently between the gap evaluated and measured by the visual inspection with the gap assessed using the scanner. **Results:** The reproducibility of the score systems used to assess secondary caries reached high values. Spearman's correlation coefficients (Rho; 95%CI) between the following variables versus histology were: FDI presence of caries (0.65; 0.53 to 0.74); CARS scores (0.65; 0.52 to 0.74); FDI treatment decision (0.46; 0.31 to 0.59); and CARS treatment decision (0.62 0.49 to 0.72). Rho (95%CI) between histological assessment and the gap assessment by the visual inspection was 0.59 (0.45 to 0.70), with the gap measurement by the visual inspection was 0.49 (0.33 to 0.62), and the gap measured by the scanner was 0.37 (0.18 to 0.53). **Conclusion:** Both visual criteria systems present similar performance in detecting caries lesions around restorations and are moderately correlated with lesion depth, with a slight CARS superiority. However, the 3D intraoral scanner does not add further information to gap size assessment than visual inspection.

6.1 Introduction

Caries around restoration is considered one of the most frequent causes of restoration failure [1]. Although the term "secondary caries" is still frequently used, these lesions seem to be similar to primary caries located at the margin of a restoration [2]. However, the diagnosis of secondary caries is always more difficult than that of primary caries due to the presence of the restoration [3]. Moreover, it has been probably overestimated by dentists since there are differences in the rates of secondary caries reported in practice-based cross-sectional studies versus longitudinal studies [2].

The visual inspection, visual-tactile examination, and radiographic method are the most common methods used for secondary caries assessment [4-6]. However, visual detection is challenging because secondary caries lesions can be misinterpreted with small defects such as brown and black marginal staining and residual carious lesions left behind when applying conservative operative techniques [7,8]. On the other hand, the radiographic method may underestimate the caries lesion extension [9] and is influenced by the radiopacity of the restorative material [10]. It leads to misinterpretations due to the difficulty in differentiating between the restorative material and tooth tissue [10]. Besides, x-rays are limited in their two-dimensional nature, which depends on the beam's angulation and superimposition of details in the radiograph [3]. The use of cone-beam computed tomography has been investigated and could improve the caries lesions assessment [11], but it would not be indicated for this purpose due to high doses of ionizing radiation.

To overcome these challenges, the use of visual diagnostic criteria has been proposed to improve the objectivity of the clinical examination, and the use of promising alternative detection techniques have also been suggested. Regarding the visual criteria, two of them were proposed to being used in research and in the clinical practice: the criteria developed by the International Dental Federation (FDI) [12] and the Caries Associated with Restorations and Sealants (CARS) [13]. The CARS criteria have been integrated into the Caries Classification and Management System (ICCMS) and is described in the recent publication of the CariesCare 4D [14]. Nevertheless, there is a lack of evidence about the accuracy and impact of their use on caries around restoration assessment in permanent teeth.

Regarding the use of alternative detection techniques, the increasing use of the three-dimensional (3D) intraoral scanners in clinical practice created an opportunity to use it for diagnostic purposes as well [15]. Compared to the most common methods currently used, the digital 3D model technology presents the strong points of providing large magnification of dentition than the visual inspection and is free from ionizing radiation [16]. The 3D intraoral scanner has been recently proposed for the occlusal caries diagnosis of extracted posterior teeth in an in vitro study, and the results showed similar accuracy compared to the visual examination [17]. However, to the best of our knowledge, the use of the 3D intraoral scanner for caries around restoration assessment has not been evaluated yet.

Therefore, this paper aims to evaluate the in vitro performance of the 3D intraoral scanner and two visual criteria systems, the FDI and the CARS criteria, in detecting caries lesions and predict their severity around composite restorations in permanent posterior teeth. Our working hypothesis is that the 3D intraoral scanner presents the best performance in assessing caries around composite restoration compared to both visual criteria.

6.2 Materials and Methods

Study design and sample selection

The present study was designed to compare the performance of three different methods in detecting caries and predict its severity around composite restorations in permanent extracted teeth. These methods are the International Dental Federation (FDI) criteria, the Caries Associated with Restorations and Sealants (CARS) system, and the 3D intraoral scanner (TRIOS 4, 3Shape TRIOS A/S, Denmark). One examiner performed the visual assessment with both criteria systems. Another examiner conducted the 3D scanner evaluation. The researchers were blind to each other. Besides, half of the sample was randomly selected and re-assessed with each diagnostic method to assess the weighted kappa value before the beginning of the study. The restoration assessment started after the intra-examiner weighted kappa value reached values greater than 0.75 for the FDI criteria, CARS method and the 3D intraoral scanner.

The sample was composed of extracted permanent teeth of unknown history donated by the bank of human teeth of the School of Dentistry from the University of Copenhagen. There are no restrictions in using extracted teeth for research in the laboratory of this University. From a batch of 500 extracted teeth stored in 0.1% thymol water, those with composite restorations were selected by an external examiner for further investigation. The teeth were classified as occlusal restoration, occlusal-approximal or as multisurface composite restoration. All restorations surfaces were visually assessed and the one that presents the most severe defect (poor marginal adaptation, presence of caries lesion around it or marginal staining) was selected for further investigation. Images of the selected surfaces were taken using a Discovery V8 stereomicroscope (Zeiss, Jena, Germany) with a connected Infinity X (DeltaPix, Ontario, Canada) digital camera (Figure 1).

For sample size calculation, we considered an anticipated correlation coefficient of 0.30, considering a level of significance of 0.05 and a power of 80%. We added 20% to the sample considering the use of a non-parametric approach, since some diagnostic methods would provide ordinal scores. Thus, we reached a minimum sample of 101 teeth.

Visual examination

A trained and calibrated researcher (B.L.P.M.) conducted the visual examination. Since a randomized clinical trial is being carried out simultaneously to investigate the use of the FDI and CARS criteria, more details about the training can be found in a previous publication [18]. Firstly, the researcher assessed the presence of plaque around the restoration using a ballpoint probe. It was scored as 0 (no plaque) or 1 (presence of plaque). Then, the presence of a gap between the tooth and the restorations was evaluated using the same ballpoint probe. It was scored as 0 (no gap), 1 (presence of gap without any content inside), 2 (presence of plaque inside the gap) or 3 (presence of soft dentin inside the gap). The gap size was also measured by a millimeter probe and classified as 0 (gap ≤ 1mm) or 1 (gap > 1mm).

Then, after the teeth were cleaned with the aid of a rotating bristle brush and water slurry, the caries assessment was conducted by both visual methods by the same examiner. The order that the examiner used the methods was determined by random allocation. A random sequence with blocks of different sizes (2, 4, 6 or 8)

was generated in the platform www.sealedenvelope.com. Thus, restoration evaluation was first performed with the allocated group. After reaching the treatment decision, the examiner (B.L.P.M.) conducted a second evaluation according to the other criteria. The visual examination was done using two different visual methods:

- FDI criteria: diagnosis and treatment decision as described in the International Dental Federation (FDI) criteria [12].
- CARS system: diagnosis according to Caries Associated with Restorations or Sealants (CARS) detection criteria, described in the ICCMS [13] and CariesCare International 4D [Martignon et al., 2019]. The proposed treatment decision was based on the definitions of primary caries described in the CariesCare International 4D [14]. The characteristics of activity for primary caries from the same health outcomes-focused system were also used in association.

Three of the sixteen subcategories presented by the original system were selected to use among the FDI criteria: marginal staining, marginal adaptation, and recurrence of caries. The marginal staining was evaluated based on the fact that it can be misinterpreted with the presence of caries lesion around restoration besides being clinically a reason for restoration reintervention in daily clinical practice [19]. Therefore, the parameter marginal adaptation was included in this study since a defective marginal adaptation can allow biofilm accumulation and consequently demineralization along the restored tooth cavity wall [20]. Each of the three subcategories selected is scored according to a five-step grading of the restoration, and the final score is the highest score obtained among then. The detailed description of the FDI criteria used in this study is presented in Appendix A in Online Supplementary Material.

Regarding the CARS criteria, it was derived from the International Caries Detection and Assessment System (ICDAS) [21], developed for the assessment of primary caries lesions. The detailed description of the CARS system can be found in Appendix B in Online Supplementary Material. Besides, the definitions and characteristics of active and inactive lesions for primary caries evaluation from CariesCare International 4D also used in association with the CARS criteria can be found in Appendix C of the Online Supplementary Material. Nevertheless, this system does not present any treatment decision linked to the evaluation method. For this reason, the decisions based on the ICCMS recommendations for treating primary

caries lesions were adapted to propose treatment decisions to caries around restorations. The recommendations of clinical guidelines for treating direct restorations based on the minimal intervention dentistry were also considered in developing the CARS treatment decision [22, 23]. This treatment decision matrix is presented in Appendix D (Online Supplementary Material).

The treatment decisions for the evaluated restorations according to the FDI and CARS criteria were classified into: no treatment (without necessary intervention and follow-up of the restoration over time), professional topical fluoride application (as a treatment for non-cavitated active caries lesions detected by the CARS criteria), refurbishment (finishing and polishing of the restoration), repair (a minimally invasive approach that implies, in any case, the addition of a restorative material, with or without preparation in the restoration and/or dental hard tissues) [22] and replacement (complete removal of the restoration) [22].

3D Intraoral scanner evaluation

The selected teeth were individually scanned by a 3D intraoral scanner (TRIOS 4, 3Shape TRIOS A/S, Denmark). A silicon base was prepared for each tooth to standardize the process and maintain it in the same position when the teeth were scanned. An experienced researcher (S.M.) in using this digital technology performed the evaluation in the present study.

By scanning with white light, images from the tooth crown were captured using the 3D color imaging mode of a high-definition hand-held intraoral scanner (Figure 2). Afterwards, color texture was removed since it was easier to assess the presence of gap around restoration. This process was done with all teeth and images from the selected surfaces were captured again (Figure 3). The blue light (415 nm wavelength) emitted by the same scanner was used in this study. However, this fluorescence imaging did not add further information in the evaluations. This was probably due to the fact that the teeth had been stored for a long time in liquid storage solution and must had resulted to diffusion of bacteria and their metabolites form the caries lesions in the storage solution [24].

Gap sizes on the teeth 3D models were also assessed using specific software, TRIOS Patient monitoring (Version 2.1.2.8, 3Shape TRIOS A/S, Copenhagen, Denmark). The measurements were taken at the position with the widest visible gap

around the restoration using a cross-sections tool available in the software (Figure 4) and expressed in mm (≥0.01 mm). All study images were processed with 3Shape TRIOS and Dental Desktop software (Versions 1.18.3.9 and 1.7.1.0 respectively, 3Shape A/S, Copenhagen, Denmark).

Reference standard method

The reference standard considered for validation of the methods was the histological examination of hemisections through the site using a Discovery V8 stereomicroscope (Zeiss, Jena, Germany) with a connected Infinity X (DeltaPix, Ontario, Canada) digital camera (Figure 5). Each tooth was hemi-sectioned through the area of interest perpendicular to the occlusal surface according to each lesion (Microtrenn, Hofer, using a 100 m thick copper disk). After that, the same examiner who conducted the visual examination (B.L.P.M.) took photos of the hemisection through the site using the stereomicroscope (x5) and the area of interest was marked on each photo. Then, an experienced examiner in caries research (K.R.E.) conducted the histological examination. The researcher was calibrated before the beginning of the study and the intra-examiner weighted kappa value reached value greater than 0.75.

A 4-point scale was used to evaluate lesion depth: D0 (no secondary caries); D1 (secondary caries lesion detected in enamel or outer third of dentin); D2 (secondary caries lesion detected in the middle third of dentin); D3 (secondary caries lesion detected in the inner third of dentin). The deepest score for each investigation site was used in the subsequent analyses.

Data analysis

Firstly, unweighted and weighted kappa tests were conducted to assess the intra-examiner reproducibility of the scoring system used for the FDI criteria, CARS system, and histological examination. For the gap measurement reproducibility assessed by the 3D intraoral scanner, Intraclass correlation coefficient was calculated. Spearman's rank correlation analyses were then conducted between the scores obtained with the FDI parameters for marginal staining, marginal adaptation, presence of caries, and CARS criteria with the histological examination. For this

approach, Spearman's correlation coefficient (Rho) and respective 95% confidence intervals (95%CIs) were calculated separately for each considered evaluation parameter. The treatment decisions regarding the restorations obtained with both FDI and CARS criteria were categorized into: (i) no treatment, (ii) non-operative treatment, (iii) repair or refurbishment, and (iv) replacement. Restorations classified as without intervention's need were included in category (i) and those assigned to receive topical fluoride application by the CARS system were included in category (ii). Spearman's correlation analyses were conducted between FDI and CARS treatment decisions with histological examination.

Afterward, the gap evaluation performed by the visual inspection was categorized into: (i) no visual gap, (ii) only gap with no biofilm or dentin exposed, (iii) gap with biofilm and (iv) gap with dentin exposed. Then, the gap measured by the visual inspection was categorized into: (i) no visual gap, (ii) gap measuring up to 1 mm and (iii) gap measuring more than 1 mm. In contrast, the mean and standard deviation were calculated for the gap measurement performed by the 3D intraoral scanner. For this approach, Rho and 95% CIs were calculated separately between each strategy used for the gap evaluation and the histological examination. Spearman's rank correlation analyses were also conducted independently between the gap assessed by the visual inspection and measured by the 3D intraoral scanner, and the gap measured by the visual inspection with the gap measured by the 3D intraoral scanner.

6.3 Results

The sample was composed of 116 teeth, being 83 (71.5%) permanent molars and 33 (28.5%) premolars. Fifteen teeth (13%) were classified as occlusal restorations, 37 (31.9%) were approximal restorations, and 64 (55.1%) were classified as multisurface restorations. The intra-examiner reproducibility of the visual systems used to assess caries lesions around composite restorations in the present study reached weighted kappa values higher than 0.8 for most parameters assessed with two methods and the reference standard (Table 1). Also, the Intraclass correlation coefficient of the gap measurement assessed by the 3D intraoral scanner was excellent (Table 1).

The correlation between lesion depth and the scores obtained with the FDI and CARS methods and the activity status evaluation are presented in Table 2. Criteria with higher correlation values were the presence of caries assessed by the FDI criteria and the scores obtained with the CARS system. Adaptation evaluated with the FDI and caries activity assessed by the CARS method were moderately correlated with the lesion depth assessed through histological evaluation (Table 2). Otherwise, the marginal staining evaluation performed with the FDI method showed a non-significant correlation with the lesion depth (Table 2). Regarding the treatment decision obtained with both visual methods, correlation with lesion depth was moderate for FDI and CARS methods, although slightly higher for the CARS system (Table 3).

Moreover, we found that a higher correlation with the lesion depth was obtained by the visual examination when the content inside the gap was assessed during the visual evaluation, followed by the measurement performed by the visual inspection (Table 4). In contrast, the 3D intraoral scanner gap measurement showed the weakest correlation with the histological examination (Table 4). Additionally, the correlations between the visual assessment of the content inside the gap and the visual measurement performed with the visual inspection were similar and moderately correlated with the 3D intraoral scanner gap's measure (Table 5).

6.4 Discussion

Secondary caries represents a significant clinical problem since it is considered one of the main reasons for restorations failure and reintervention in permanent posterior teeth [25]. Many studies have pointed inconsistency in the detection of this condition [26]. For this reason, diagnostic strategies and devices that offer the ability to discriminate caries without subjecting patients to overtreatment still need to be investigated [27]. To the best of our knowledge, this study compared for the first time, the use of a new promising technology device, the 3D intraoral scanner, with two detailed diagnostic visual criteria for the detection of secondary caries around composite restorations of permanent teeth in an in vitro study.

It was observed that the FDI and CARS methods had similar performance when the presence of caries lesion around the restorations was evaluated. Besides, both criteria were moderately correlated to the lesion depth. The description of the scores

of the FDI and CARS criteria to assess secondary caries is similar. This fact is probably the explanation for the results found in this study. The FDI criteria seems to be a practical, relevant, and standardized system, and an increase in its use has been observed since 2010 [28]. The use of this method is related to the study's objective since the researchers can select the most relevant parameters for the restoration assessment instead of the original 16 available [28]. However, the FDI marginal adaptation and the FDI marginal staining did not seem to be a good predictor of caries around restoration according to the results found in this study, mainly the presence of staining. This is in accordance with many studies that have shown that staining around restorations is not a predictor of caries [29, 7], even being often mistakenly associated with the presence of a lesion leading to an overtreatment [19]. For this reason, the treatment decisions linked to the CARS system presented a higher correlation to the histology than the FDI criteria. Findings obtained in primary teeth also observed that staining and marginal adaptation are not good parameters to be evaluated in the diagnostic strategy for restoration assessment [30].

The CARS system is focused on the caries assessment. This system is a well-described criterion derived from the International Caries Detection and Assessment System (ICDAS) [21]. Although it presents strong points as the description of lesion severity, the differentiation of amalgam shadows from caries lesions, and the assessment of presence or absence of demineralization around the restoration, its use in studies related to restorative materials is limited [19]. On the other hand, the system does not present any treatment decision linked to the caries assessment, and it should be used associated with a system for assessing lesion activity. Nevertheless, we found a moderate correlation between the caries activity status and the reference standard. It was probably not found a higher correlation due to a weakness inherent in the study design since extracted teeth were used, and some could be stored for a long time. In this way, there were no relevant clinical signs available to estimate lesion activity, as the guaranteed presence of biofilm (although it was one of the evaluated parameters of the study) and the condition of the gingiva [31]. Even the lesion characteristics, such as texture, hardness, and appearance, could be altered.

Regarding the 3D intraoral scanner for assessing secondary caries lesion, as it has not a criterion linked to being used in the assessment, we used the technology to evaluate the gap and its measurement. A gap may originate through polymerization

shrinkage due to failure to obtain satisfactory adaptation and insufficient bond of the restoration [3]. According to recent studies, gaps without detectable demineralization cannot be considered as any stage of secondary caries [32]. However, in the past, researchers have stated that defects on marginal adaptation of restorations can predispose demineralization due to microleakage of bacteria, their metabolites, and compounds from the oral fluids [33, 34]. More recent evidence from in vitro and in vivo studies suggests that microleakage can result in the cavity-wall lesion [35, 36]; however, there is no conclusive answer to the relationship between gap size and wall lesion development, especially the minimum gap size needed for its development. Considering the caries process, the lesion development would occur where a biofilm could establish along with the interface between tooth and restoration [37].

Apart from the controversial discussion around the association between gaps and secondary caries, the 3D intraoral scanner assessment did not present better performance than the gap evaluation's visual examination. The higher correlation between the presence of gap and histology was derived from the visual inspection associated with evaluating the content inside the gap. The evaluation of biofilm and dentin's presence could bring more objective to the assessment as the reference standard is the caries lesion depth. We believe that the 3D intraoral scanner performance could be improved if the assessment would be done in association with the visual-tactile examination of the restoration for the detection of caries around it.

Although the 3D intraoral scanner seems not bring many advantages for diagnosing secondary caries and predicting its severity according to the results presented, the method would have some advantages. The 3D intraoral scanner captured images probably allow monitoring caries lesion progression and small defects presented by the restorations when the decision-making is to perform no treatment and reassess it in the follow-up appointments. The less invasive treatment decisions, as the monitoring, refurbishment, and repair are being recommended to be adopted whenever possible in the daily clinical practice instead of the restoration replacement [14, 23, 38]. In this way, the conventional visual inspection does not provide an image record of the teeth. Another possible advantage in using the images provided by the 3D intraoral scanner for remote discussions between clinicians of different locations. Telemedicine and teledentistry are being encouraged, especially for educational and diagnosis propose [39]. The actual COVID-19 pandemic has shown the need to incorporate teledentistry into the routine of dental

practice [40]. Therefore, the treatment decision could be reached by direct visual inspection and 3D intraoral scanner could be used as adjunct method, mainly due to the advantages abovementioned.

For the present moment, the use of standardized diagnostic criteria for the assessment of caries around restoration should be encouraged to avoid diagnostic errors and overtreatment [3]. The selected criteria should present the best treatment option for managing restorations, ensuring the best health outcome for the patient [41]. In this way, randomized clinical trials should be developed considering relevant health outcome for the patient. The CARS system used in association with a system for assessing lesion activity and considering the authors' treatment decision seems to be reasonable criteria to be used in clinical practice for the assessment of caries around restorations.

In conclusion, the FDI criteria and the CARS system are associated with lesion depth, and both systems perform similarly for the detection of caries lesions around composite restoration. The 3D intraoral scanner does not add further information to the gap size visually assessed.

Acknowledgement

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Statement of Ethics

No ethical approval from the National Committee on Health Research Ethics was needed for the current study. The human teeth, extracted for therapeutic reasons, were collected as anonymous leftover biological material at the Department of Odontology of the University of Copenhagen.

Disclosure Statement

The author (S.M.) is employed at 3Shape TRIOS A/S. Her salary is partially covered by 3ShapeTRIOS A/S and by funding from Innovation Fund Denmark, respectively. The other authors have no conflicts of interest to declare.

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Author Contributions

The first author (B.L.P.M.) was responsible for overall study planning, data collection, and article drafting. The experiments were conducted by the first author and the researchers at the University of Copenhagen (S.M. and K.R.E.). The researcher (F.M.M.) was responsible for data analysis. All authors (B.L.P.M., S.M., A.R.B., M.S.C., F.M.M., K.R.E.) contributed to the study design, the data interpretation, and the article draft.

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Table 1 - Intra-examiner reproducibility of the scoring system used for the International Dental Federation (FDI) criteria, the Caries Associated with Restorations and Sealants (CARS) system, histological examination, and the gap measurement assessed by the three-dimensional intraoral scanner

	Unweighted kappa	Weighted kappa *
FDI parameters		
Staining	0.548 (0.317 to 0.779)	0.860 (0.762 to 0.957)
Adaptation	0.869 (0.730 to 1.000)	0.967 (0.928 to 1.000)
Presence of caries	0.818 (0.656 to 0.980)	0.920 (0.803 to 1.000)
Treatment decision	0.749 (0.552 to 0.947)	0.790 (0.572 to 1.000)
CARS parameters		
Scores	0.907 (0.785 to 1.000)	0.986 (0.967 to 1.000)
Activity status	0.865 (0.686 to 1.000)	**
Treatment decision	0.835 (0.662 to 1.000)	0.890 (0.762 to 1.000)
Histological scores	0.823 (0.662 to 0.984)	0.945 (0.892 to 0.998)
Scanner parameter		
	Intraclass correlation coefficient	
Gap measurement	0.958 (0.929 to 0.976)	

Figures between parenthesis are 95% confidence intervals
* weighted kappa using quadratic approach.
** not applicable because it is a dichotomous variable

Source: The author

Table 2 - Relationship and correlation among scores obtained by the International Dental Federation (FDI) criteria, the Caries Associated with Restorations and Sealants (CARS) system with the histological examination

Diagnostic criteria	**Histological scores**				**Total**
	0	**1**	**2**	**3**	
FDI marginal staining					
1	11	18	4	2	35
2	13	10	12	5	40
3	4	10	4	5	23
4	7	3	2	3	15
5	0	1	1	1	3
Rho = 0.138 (-0.046 to 0.312)					
FDI adaptation					
1	4	7	0	1	12
2	10	12	1	0	23
3	10	9	3	0	22
4	8	10	8	4	30
5	3	4	11	11	29
Rho = 0.483 (0.329 to 0.611)					
FDI presence of caries					
1	29	28	6	1	64
2	3	5	0	0	8
3	2	3	0	0	5
4	1	5	13	5	24
5	0	1	4	10	15
Rho = 0.648 (0.527 to 0.742)					
CARS scores					
0	29	28	6	1	64
1	0	0	0	0	0
2	3	4	0	0	7
3	2	4	0	0	6
4	0	0	0	0	0
5	1	5	12	6	24
6	0	1	5	9	15
Rho = 0.645 (0.524 to 0.740)					
Cars activity status					
Sound or inactive	32	35	14	3	84
Active	3	7	9	13	32
Rho = 0.470 (0.315 to 0.601)					
Total	**35**	**42**	**23**	**16**	**116**

Rho = Spearman correlation coefficient
Figures in parenthesis are 95% confidence intervals

Source: The author

Table 3 - Correlation among treatment decision reached by the International Dental Federation (FDI) criteria, the Caries Associated with Restorations and Sealants (CARS) system with the histological scores

Treatment decision	**Histological scores**				**Total**
	0	**1**	**2**	**3**	
FDI treatment decision					
No treatment	17	23	2	1	43
Non-operative treatment	0	0	0	0	0
Repair	14	14	10	3	41
Replacement	4	5	11	12	32
Rho = 0.462 (0.306 to 0.594)					
CARS treatment decision					
No treatment	30	31	6	1	68
Non-operative treatment	2	3			
Repair	3	8	16	11	38
Replacement			1	4	5
Rho = 0.620 (0.493 to 0.721)					
Total	**35**	**42**	**23**	**16**	**116**

Rho = Spearman correlation coefficient
Figures in parenthesis are 95% confidence intervals

Source: The author

Table 4 - Correlation among the presence of gap evaluated by both visual inspection and the three-dimensional intraoral scanner, with the histological scores

Treatment decision	**Histological scores**				**Total**
	0	**1**	**2**	**3**	
GAP visual inspection					
No gap	16	21	1	0	38
Only gap with no biofilm or dentin exposed	17	13	9	1	40
Gap with biofilm	2	3	5	0	10
Gap with dentin exposed		5	8	12	27
Total	35	42	23	15	115
Rho = 0.586 (0.452 to 0.695)					
Gap measurement by visual inspection					
Gap absent	16	21	1	0	38
Gap measuring up to 1 mm	13	14	9	1	37
Gap measuring more than 1 mm	6	6	11	14	37
	35	41	21	15	112
Rho = 0.486 (0.330 to 0.616)					
Gap measurement by scanner (mm)					
Mean (Standard deviation)	0.49 (1.10)	0.47 (0.48)	1.40 (1.49)	1.45 (1.89)	0.78 (1.21)
Rho = 0.371 (0.184 to 0.533)					
Rho = Spearman correlation coefficient Figures in parenthesis are 95% confidence intervals					

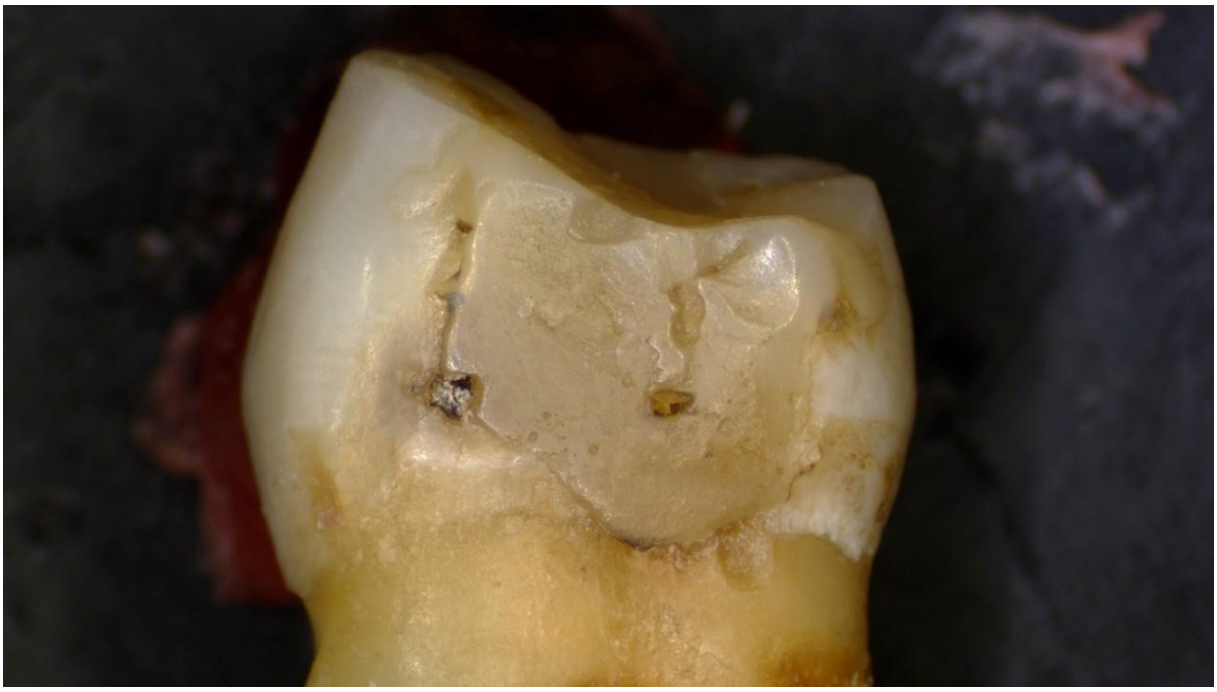
Source: The author

Table 5 - Correlation among the presence of gap and gap measurement evaluated by visual inspection with the three-dimensional intraoral scanner

	Gap measurement by scanner (mm)		
	Mean	SD	Rho (95% CI)
GAP visual inspection			0.531 (0.369 to 0.662)
No gap	0.19	0.44	
Only gap with no biofilm or dentin exposed	0.83	1.03	
Gap with biofilm	0.55	0.55	
Gap with dentin exposed	1.69	1.83	
Total	0.78	1.21	
Gap measurement by visual inspection			0.495 (0.325 to 0.635)
Gap absent	0.19	0.44	
Gap measuring up to 1 mm	0.64	0.44	
Gap measuring more than 1 mm	1.55	1.85	
Total	0.77	1.22	
SD = standard deviation; Rho = Spearman correlation coefficient; 95% CI = 95% confidence intervals			

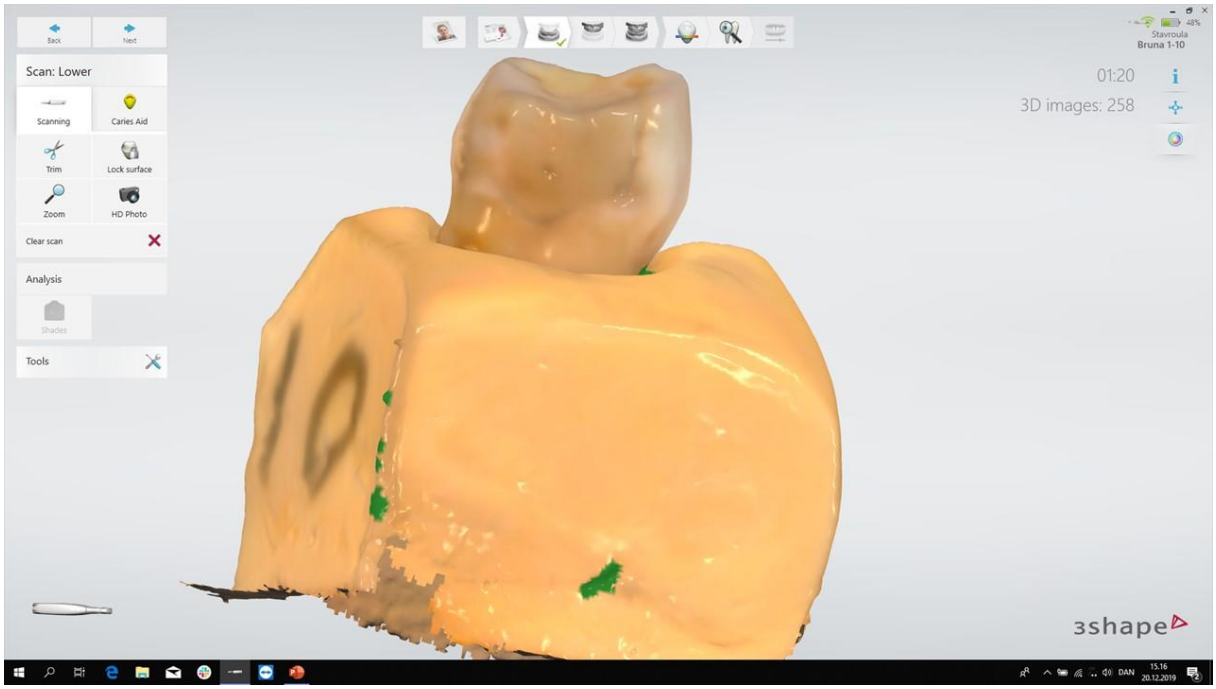
Source: The author

Figure 1 - Image of the selected surface taken using the stereomicroscope to be assessed with the diagnostic methods



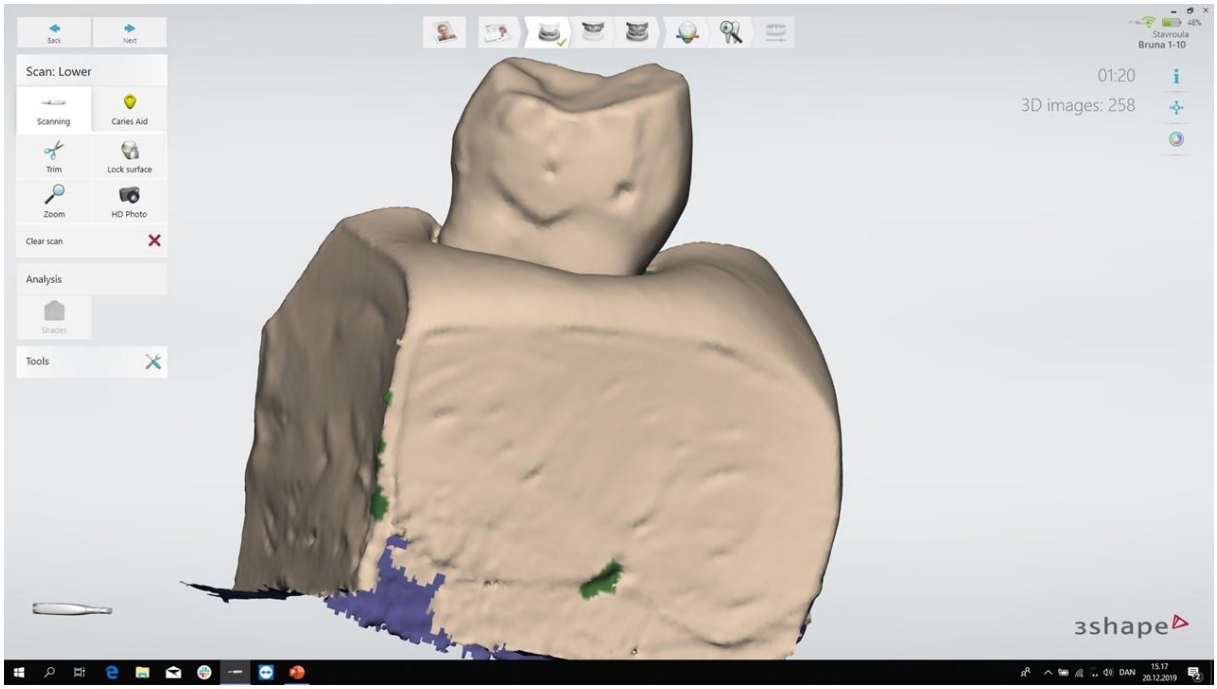
Source: The author

Figure. 2 - The captured image of the selected surface scanned with the white light of the 3D intraoral scanner



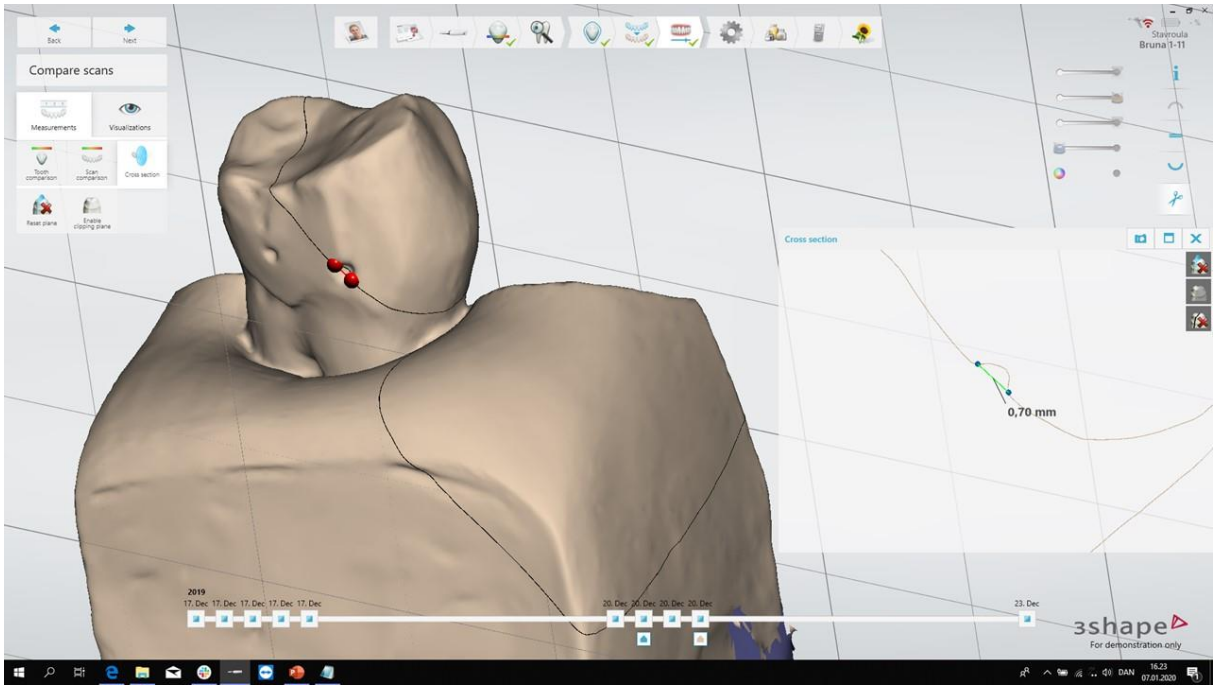
Source: The author

Figure. 3 - Captured image from the selected surface scanned with the 3D intraoral scanner after removing the colour texture



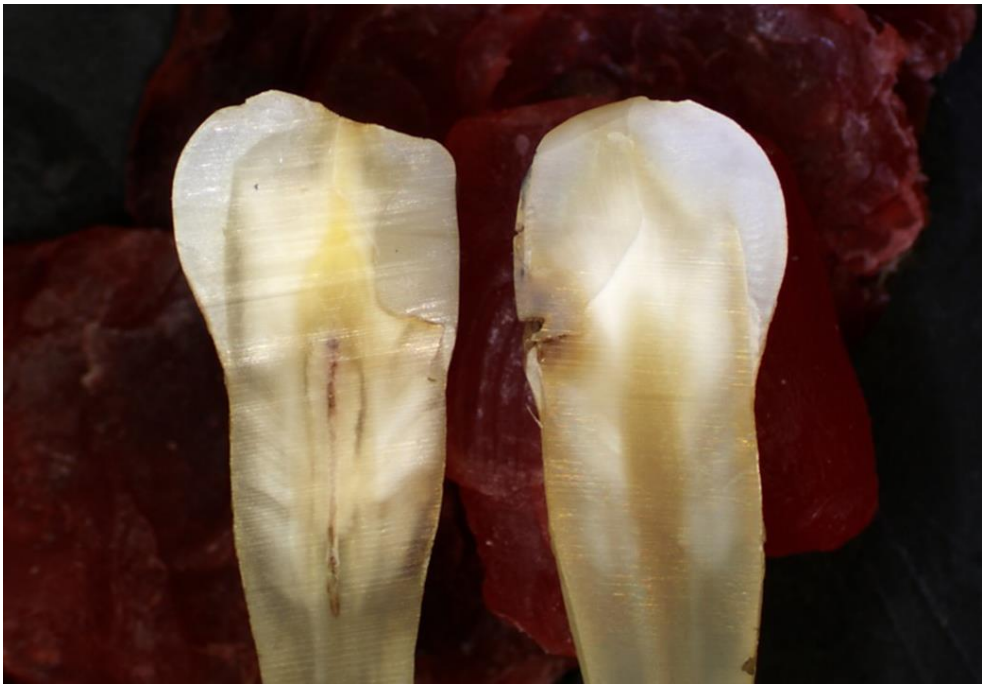
Source: The author

Figure. 4 - The captured image of the gap measurement using specific software (TRIOS – Dental Desktop, 3Shape A/S, Denmark) after the tooth has been scanned



Source: The author

Figure. 5 - Image of the histological examination of hemisections through the site using a stereomicroscope as the study's reference standard



Source: The author

APPENDIX A - Table 1. International Dental Federation (FDI) criteria linked to the treatment decision

FDI scores					FDI treatment
Scores	**Classification**	**Marginal staining***	**Marginal adaptation**	**Recurrence of caries**	**Indication**
1	**Clinically excellent/ very good**	No marginal staining.	Harmonious outline, no gaps, no white or discolored lines	No secondary or primary caries	No treatment
2	**Clinically good**	Minor marginal staining, easily removable by polishing.	Marginal gap (<150 µm), white lines. Small marginal fracture removable by polishing. Slight ditching, slight step/flashes, minor irregularities. Gap < 250µm not removable.	Very small and localized demineralization	No treatment
3	**Clinically sufficient/ satisfactory**	Moderate marginal staining, not esthetically unacceptable.	Several small marginal fractures. Major irregularities, ditching or flash, steps. Gap > 250µm or dentine/base exposed.	Larger areas of demineralisation	No treatment
4	**Clinically unsatisfactory**	Pronounced marginal staining; major intervention necessary for improvement.	Severe ditching or marginal fractures. Larger irregularities or steps.	Caries with cavitation	Repair
5	**Clinically poor**	Deep marginal staining, not accessible for intervention.	Restoration (complete or partial) is loose but in situ. Generalized major gaps or irregularities.	Deep secondary caries or exposed dentine that is not accessible for repair of restoration.	Replacement

Source: The author

APPENDIX B - Table 2. Caries Associated with Restorations and Sealants (CARS) Criteria

Caries Associated with Restorations and Sealants codes		
Code 0	**Sound tooth surface with restoration or sealant**	A sound tooth surface adjacent to a restoration/sealant margin. There should be no evidence of caries (either no or questionable change in enamel translucency after prolonged air drying for 5 seconds). Surfaces with marginal defects less than 0.5mm in width (i.e. will not admit the ball end of the CPI Probe), developmental defects such as enamel hypoplasia fluorosis; tooth wear (attrition, abrasion and erosion), and extrinsic or intrinsic stains will be recorded as sound. Stained margins consistent with non-carious habits (e.g. frequent tea drinking) and which do not exhibit signs consistent with demineralization should be scored as sound.
Code 1	**First visual change in enamel**	When seen wet there is no evidence of any change in color attributable to carious activity, but after prolonged air drying (for approximately 5 seconds) an opacity or discoloration consistent with demineralization is visible that is not consistent with the clinical appearance of sound enamel.
Code 2	**Distinct visual change in enamel/dentin adjacent to a restoration margin**	If the restoration margin is placed on enamel the tooth must be viewed wet. When wet there is an opacity consistent with demineralization or discoloration that is not consistent with the clinical appearance of sound enamel (Note: the lesion is still visible when dry). If the restoration margin is placed on dentin: Code 2 applies to discoloration that is not consistent with the clinical appearance of sound dentin or cementum.
Code 3	**Carious defects of <0.5 mm with the signs of code 2**	Cavitation at the margin of the restoration/sealant less than 0.5mm, in addition to either an opacity or discoloration consistent with demineralization that is not consistent with the clinical appearance of sound enamel or with a shadow of discolored dentin.
Code 4	**Marginal caries in enamel/dentin /cementum adjacent to restoration with underlying dark shadow from dentin**	The tooth surface may have characteristics of code 2 and has a shadow of discolored dentin which is visible through an apparently intact enamel surface or with localized breakdown in enamel but no visible dentin. This appearance is often seen more easily when the tooth is wet and is a darkening and intrinsic shadow which may be grey, blue, orange, or brown in color. Note: view tooth wet and then dry. This lesion should be distinguished from amalgam shadows.
Code 5	**Distinct cavity adjacent to restoration**	Distinct cavity adjacent to restoration/sealant with visible dentin in the interfacial space with signs of caries as described in code 4, in addition to a gap > 0.5mm in width. OR In those instances where margins are not visible, there is evidence of discontinuity at the margin of the restoration/sealant and tooth substance of the dentin as detected by 0.5mm ball-ended probe run along the restoration/sealant margin.
Code 6	**Extensive distinct cavity with visible dentin**	Obvious loss of tooth structure, the extensive cavity may be deep or wide and dentin is clearly visible on both the walls and at the base.

Source: The author

APPENDIX C - Table 3. Characteristics of Active and Inactive Caries Linked to Caries Around Restorations System - CARS adapted

ICCMS Code	Characteristics of Lesion	
	Signs of Active Lesions	Signs of Inactive Lesions
ICCMS Initial and Moderate Caries Stage	Surface of enamel is whitish/yellowish; opaque with loss of luster, feels rough when the tip of the ball-ended probe is moved gently across the surface. Lesion is in a plaque stagnation area, i.e. in the entrance of pits and fissures, near the gingival margin or, for proximal surfaces, below or above the contact point. The lesion may be covered by thick plaque prior to cleaning.	Surface of enamel is whitish, brownish or black. Enamel may be shiny and feels hard and smooth when the tip of the ball-ended probe is moved gently across the surface. For smooth surfaces, the caries lesion is typically located at some distance from the gingival margin. Lesion may not be covered by thick plaque prior to cleaning.
ICCMS Extensive Caries Stage	Dentine feels soft or leathery on gentle probing.	Dentine is shiny and hard on gentle probing.

Source: The author

7 FINAL CONSIERATIONS

Analyzing all data presented in this thesis, we conclude that restorations in primary teeth evaluated according to the FDI criteria are more frequently indicated for replacement than when assessed by the CARS system. This diagnostic method also shows a considerable number of operative interventions, but less invasive conducts are prioritized instead of replacement, such as restoration repair or refurbishment. Besides, restorations assessed with the FDI method are more likely to be classified as having caries lesions than those evaluated by the CARS system. Regarding other variables that might influence restoration replacement, we conclude that children's caries experience and multisurface restorations influence the decision to replace restorations in primary teeth, but not the restorative dental material. Therefore, clinicians should focus on children's health-promoting to improve restoration longevity, diminishing replacement of restorations.

Regarding the accuracy of the evaluated methods for detecting caries around restoration in primary teeth, the CARS system present higher accuracy than FDI criteria. However, the FDI criteria for assessing caries' recurrence and marginal adaptation show similar performance to the CARS system when the dentin threshold is considered. These results may be explained by the fact that the lesion's severity is described similarly in both criteria and most frankly carious lesion at the filling margin also represents a gap with dentin exposure. On the other hand, the marginal staining is not an accurate parameter to evaluate secondary caries in primary teeth. In this way, it should not be used for this purpose in clinical practice.

The FDI and CARS criteria are moderately correlated with caries lesion depth when used to detect caries around composite restorations in permanent posterior teeth, with a slight CARS superiority. Both visual methods present similar performance when used for this purpose in vitro. When these methods are compared to the 3D intraoral scanner device, we saw that the 3D intraoral scanner does not add further information to gap size assessment than visual inspection. However, this alternative detection technique would present some advantages compared to the visual examination. The captured images allow monitor caries lesion and small restoration defects when the decision-making is to perform no treatment and reassess it in the follow-up appointments. Besides, with the 3D intraoral scanner, it is

possible to promote remote discussions between clinicians of different locations, especially for educational and diagnosis purposes.

In general, the CARS system seems to be more accurate. The method led to less invasive management options in assessing restorations in primary teeth and permanent teeth. However, considering the FDI criteria, the parameter for evaluating caries recurrence is very similar to the findings obtained with the CARS system, and it could be an alternative.

Nevertheless, the findings presented in this series of manuscripts were restricted to cross-sectional evaluation. The long-term impact of using the FDI and CARS criteria on relevant outcomes for children and their parents will be more appropriately assessed through the ongoing randomized clinical study. The recalls of the last follow-up evaluations were delayed due to the COVID-19 pandemic. However, the follow-up has been completed at the end of February, and we are still analyzing the data.

The findings of the two years of children's follow-up will answer the fundamental question: what the best approach for diagnosing and managing dental restorations in children is, considering the impact on the treatment decision on clinically relevant outcomes for the patient.

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ANNEX A – Ethics Committee Approval

FACULDADE DE ODONTOLOGIA USP - SÃO PAULO

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Impacto do uso de diferentes critérios clínicos na avaliação de lesões de cárie ao redor de restaurações em dentes decíduos: estudo clínico randomizado

Pesquisador: Fausto Medeiros Mendes

Área Temática:

Versão: 2

CAAE: 73013417.0.0000.0075

Instituição Proponente: Faculdade de Odontologia da Universidade de São Paulo

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 2.291.642

Apresentação do Projeto:

Trata-se de uma proposta de estudo clínico randomizado controlado com dois braços paralelos para comparar dois índices visuais de avaliação de lesões de cárie ao redor de restaurações. Em um braço, o critério de diagnóstico utilizado será o sistema proposto pela Federação Dentária Internacional (FDI) e no outro, o sistema proposto pelo International Caries Classification and Management System (ICCMS). O desfecho primário será a necessidade de intervenção operatória durante o acompanhamento das restaurações avaliadas pelos diferentes índices durante os dois anos de acompanhamento.

Objetivo da Pesquisa:

O objetivo primário do estudo é avaliar e comparar a influência da utilização de dois diferentes critérios visuais para avaliação de restaurações em dentes decíduos, sobre desfechos importantes para os pacientes a médio e a longo prazo, por meio de um estudo clínico randomizado. Estes critérios são o sistema proposto pela Federação Dentária Internacional (FDI) (Hickel et al., 2010) e pelo International Caries Classification and Management System – ICCMS (Ismail et al., 2015).

Avaliação dos Riscos e Benefícios:

Avaliação de riscos e benefícios descritos adequadamente no corpo do projeto e no TCLE.

Endereço: Av Prof Lineu Prestes 2227
Bairro: Cidade Universitária **CEP:** 05.508-900
UF: SP **Município:** SAO PAULO
Telefone: (11)3091-7960 **Fax:** (11)3091-7814 **E-mail:** cepfo@usp.br

Comentários e Considerações sobre a Pesquisa:

Projeto com proposta clara e com grande potencial para gerar evidências que colaborem na tomada de decisão clínica sobre diagnóstico de cárie ao redor de restaurações.

Considerações sobre os Termos de apresentação obrigatória:

Todos os termos apresentados: Projeto Detalhado, TCLE, Termo de Assentimento, Autorização da Clínica Odontológica, Folha de Rosto.

Recomendações:

Projeto responde a todos as recomendações da CONEP.

Tendo em vista a legislação vigente, devem ser encaminhados ao CEP-FOUSP relatórios parciais anuais referentes ao andamento da pesquisa e relatório final, utilizando-se da opção "Enviar Notificação" (descrita no Manual "Submeter Notificação", disponível na Central de Suporte - canto superior direito do site www.saude.gov.br/plataformabrasil).

Qualquer alteração no projeto original deve ser apresentada "emenda" a este CEP, de forma objetiva e com justificativas para nova apreciação.

Conclusões ou Pendências e Lista de Inadequações:

Não há pendências.

Considerações Finais a critério do CEP:

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_942976.pdf	15/09/2017 11:15:29		Aceito
Projeto Detalhado / Brochura Investigador	Projeto.pdf	15/09/2017 11:11:37	Fausto Medeiros Mendes	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE.pdf	15/09/2017 11:11:23	Fausto Medeiros Mendes	Aceito
Declaração de Pesquisadores	Carta_ao_CEP.pdf	12/09/2017 11:06:12	Fausto Medeiros Mendes	Aceito
Declaração de Instituição e Infraestrutura	Autorizacao_uso_da_clinica.pdf	03/08/2017 13:42:31	Fausto Medeiros Mendes	Aceito
TCLE / Termos de Assentimento /	Assentimento.pdf	03/08/2017 13:37:26	Fausto Medeiros Mendes	Aceito

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FACULDADE DE ODONTOLOGIA USP - SÃO PAULO

Continuação do Parecer: 2.291.642

Justificativa de Ausência	Assentimento.pdf	03/08/2017 13:37:26	Fausto Medeiros Mendes	Aceito
Folha de Rosto	Folha_de_rosto.pdf	03/08/2017 13:35:42	Fausto Medeiros Mendes	Aceito

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

SAO PAULO, 22 de Setembro de 2017

Assinado por:
Maria Gabriela Haye Biazevic
(Coordenador)

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