CÁCIA SIGNORI

Caries diagnosis and Decisions for treatment

Colofon

Caries diagnosis and Decisions for treatment

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Cácia Signori
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Promotoren
Prof. dr. M.C.D.N.J.M. Huysmans
Prof. dr. M.S. Cenci *(Universidade Federal de Pelotas, Brazil)*

Copromotor
Dr. N.J.M. Opdam

Manuscriptcommissie
Prof. dr. N.H.J. Creugers
Prof. dr. C. van Loveren *(University of Amsterdam, The Netherlands)*
Prof. dr. Annette Wiegand *(Universitätsmedizin Göttingen, Duitsland)*

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Cácia Signori
Born on February 18, 1990
in Balneário Camboriú, SC (Brazil)

Supervisor
Prof. dr. M.C.D.N.J.M. Huysmans
Prof. dr. M.S. Cenci *(Universidade Federal de Pelotas, Brazil)*

Co-supervisor
Dr. N.J.M. Opdam

Doctoral Thesis Committee
Prof. dr. N.H.J. Creugers
Prof. dr. C. van Loveren *(University of Amsterdam, The Netherlands)*
Prof. dr. Annette Wiegand *(University Medical Center Göttingen, Germany)*

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"Science means constantly walking a tightrope between blind faith and curiosity; between expertise and creativity; between bias and openness; between experience and epiphany; between ambition and passion; and between arrogance and conviction – in short, between an old today and a new tomorrow."

Heinrich Rohrer

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CHAPTER 1

General introduction

Dental practice and the challenges in the management of restorations

One of the most common procedures in dental practice is the placement and replacement of restorations due to caries. Therefore, the precision of the diagnosis, determining if the restorations are acceptable or not, impacts directly on the treatment decision [1,2] and, consequently, on the longevity of the restorations, the costs of the dental work and the time spend in the treatment [3]. Furthermore, the replacement of a restoration may accelerate the repetitive restorative cycle, causing significant loss of tissue and further impairment of the healthy dental structure [4]. Regardless the evidences above, the strategy of replacement of restorations seems to prevail over a more conservative approach, as nowadays it represents more than half of the restorative work done by dentists [5], which shows that the proper diagnosis and management of dental restorations remains an important and significant clinical problem.

Secondary caries have been reported as the main reason for restoration failure [5], being it defined as a carious lesion adjacent to an existing restoration [6], which may develop as an "external lesion" on the dental surface near to the restoration, which is similar to primary caries, or as a "wall lesion", located at the interface between the restoration and the wall of the cavity [7].

Although some studies have shown a decrease in the prevalence of primary caries lately, the same cannot be found for secondary caries on a population basis, being secondary caries often pointed out as the most common reason for the replacement of restorations. Controlled clinical trials have reported that only 2 to 3% of the failures of the restorations are due to caries [8,9], however, when we analyze the dental practices this figure is reported to be of 50-60% [5]. It is still unclear whether these differences between results in trials and routine care may be due to misdiagnosis and possible overtreatment by practitioners, or because the populations treated in trials are fundamentally different from the populations with a much higher prevalence of primary and secondary caries. This difference should be carefully analyzed before we can say it is due to overtreatment or to the prevalence of this condition, as such discrepancy may result from either a disparity between "what actually is" and "what the dentists are diagnosing as" secondary caries lesions or a difference in the prevalence of caries among the populations attending clinical studies and general practices.

The detection of secondary caries can be done by both conventional methods (visual, tactile and radiographic) and recent quantification methods (light-induced fluorescence or diode laser) [10–12], but visual and radiographic methods are still the most used ones [13,14]. The diagnosis of secondary caries by the dentist usually poses a challenge, as the clinical aspects related to this condition, such as presence of gaps at the tooth-restoration interface, opacity and discoloration of adjacent dental tissues, microleakage (observed as a

line of stain around the restoration), or presence of residual caries, which can be visualized as a grey discoloration involving the restoration [15], may be erroneously interpreted as caries lesions during the visual inspection. Bitewing radiographs are normally used for examination of interproximal areas, as visual inspection is often insufficient to establish the diagnosis, due to the presence of adjacent teeth and gingival tissue in cervical areas. Some radiographic features around the restorations may also be a confounding factor in this diagnosis, such as the radiopacity of the restorative material and the presence of bonding layer or residual caries [6,16], which may lead to false-positve and false-negative treatment decisions.

Other factors may also have been interfering in the misdiagnosis of secondary caries, such as the diversity of diagnostic criteria found in the literature and the lack of a standardized one [2]. Considering that a clinical diagnosis is a subjective process, subject to different interpretations, the existence of standardized diagnostic criteria would be useful to assist dentists, one that would use the same elements to assign the diagnosis and treatment for the restorations. Therefore, it is fundamental to investigate the characteristics of the diagnostic criteria reported in the literature and find the most appropriate clinical approach for secondary caries detection and management.

However important, few studies have evaluated the methods used for the detection of secondary caries [3], and the ones in the literature have usually looked into the accuracy of the methods. Although accuracy is a crucial aspect in the diagnosis process, studies in this area should associate the diagnostic criteria with the treatment decision, which would give them a clinical relevance. To the best of our knowledge, this was only approached in a recent study by a simulation model based on different diagnostic criteria and thresholds for secondary caries treatment.

Finally, our proposition in this thesis is to perform a systematic review to evaluate the clinical relevance of the studies regarding the accuracy of the visual and radiographic methods for secondary caries detection, and other aspects related to the diagnostic criteria used by the studies.

An alternative to teach secondary caries diagnosis in dentistry education

The quality of the education and the amount of training of the dentists seem to be some of the main factors affecting the clinical decision making in the daily practice [1]. Teaching systems are normally based on theoretical lectures [17], which pose limitations as they do not stimulate critical thinking and problem-solving abilities [18]. In an attempt to develop the competencies of the dental practitioners in the recognition and management of restorations [19], a practical training on the detection and management of secondary

caries, in the undergraduate curriculum, allied to theoretical knowledge would be an interesting alternative.

The use of human teeth is the best alternative to teach students at preclinical level, as they reflect more closely the situations found in the clinic [20]. However, due to the difficulty to obtain extracted teeth with different stages of secondary caries progression, other alternatives, based on current knowledge, need to be employed. One of these alternatives is to artificially develop caries lesions around restorations in natural teeth in the laboratory, which was already reported in previous studies [21,22]. This technique was used as part of the experiment made on this thesis that evaluated a new way of teaching dental students to approach critical procedures, such as the assessment and management of caries and marginal defects around restorations. As part of this thesis, we performed a controlled randomized study to investigate the contribution of a laboratorial training on the learning process of undergraduate students regarding their ability to diagnose and manage restorations.

An alternative to restoration assessment in dental research

Lately, there has been an increase in the number of clinical studies analyzing the outcome of restorative procedures, which are usually about the longevity of the restorations. A considerable part of these studies has been based on data from general dental practice networks (PBRN). This type of study allows the research to evaluate the outcomes generated in a real scenario, and it also gives the research access to a representative number of cases and follow-up data [23]. However, several types of bias may be present in these type of studies, mainly because dental practitioners do not receive a previous training about the diagnosis and treatment of the restorations [24]. As a result, differences among dentists regarding the decision to intervene in a restoration are often reported [25].

In addition, the criteria used to evaluated the quality of the restorations, given mainly by the FDI World Dental Federation [26] and the modified US Public Health Service (USPHS)/ Ryge criteria [27], are complex to be used by dental practitioners and they are intended to be used to detect small differences on dental restorations in clinical studies, and even then, these criteria may be subject to different interpretations.

In order to reduce the risk of bias, one alternative is to use digital photographs in PBRN to help in the assessment of the quality of the restorations. The photograph produced by general dental practitioners (GDPs) could be evaluated by independent investigators in an attempt to reduce the variability of the results. The intraoral digital photography was considered as an adequate tool for the diagnosis of dental conditions, such as tooth decay [28], dental trauma [29] and in the evaluation of dental restorations [30,31], being qualified as a significant source of information. Therefore, we also investigated the validity of intraoral digital photography in the assessment of dental restorations in this thesis.

Decision-Making

Differences among dentists regarding decision-making have been widely reported by several studies [1,32,33]. The dentists do not seem to share a common understanding on the diagnosis and management of restorations. The explanations for such disparities have still been unclear, which highlights the importance of studies about the factors related to this process, and studies about how dentists are diagnosing and treating caries around restorations. Several studies have investigated the treatment decision regarding the diagnosis of primary caries [34–36], whereas a limited number have evaluated the diagnosis and decision-making in restored teeth [37,38]. It is necessary to elucidate the reasons behind the decision to intervene on a defective restoration, as it would improve the treatment decision and ensure the patient would receive the best option of treatment [39], avoiding overtreatment.

The conduct of dentists related to their clinical decision-making for cases of secondary caries around crowns margins is highly heterogeneous [1]. And it is mainly influenced by the size of the lesion, tooth vitality, educational training and experience level. It is also suggested that the age, country of qualification of the dentist and employment status influence on the longevity of the restoration [40]. The differences of the dentists approaches has been reinforced by the fact that an increase in the chance of replacement of the restorations was observed in patients who changed dentists [41]. In addition, the decision to replace a restoration may be influenced by a more or less conservative attitude of the dentist [42].

A recent consensus paper recommended that the intervention on a defective restoration should be the last resort, favoring more conservative approaches, such as monitoring, refurbishment and repair [2]. This more conservative approach has been widely taught in the academic environment, however it is not clear to what extent this approach is been reflected in the dental treatment decisions by the dentists in their daily routine. A situation illustrating this shows that, although the concept of repairing restorations has been taught by the majority of dental schools, and dentists have been aware of the recommendations regarding less invasive treatments, the proportion of repaired restorations is still low [43,44] and more invasive conducts has been reported [33,42]. However, it has also been reported that recent dental graduates tend to adopt a more conservative approach [33]. It is still unclear if dental practitioners and the professionals from the universities share a common understanding regarding the needs for restorative interventions. In this thesis we compared the clinical decision-making based on the analysis of bitewings made by GDPs and experts in cariology and restorative dentistry regarding restored surfaces.

Besides the role of the dentist in the diagnosis and treatment decision, characteristics of the patients, such as socioeconomic level, oral hygiene, caries risk and parafunctional

habits also play a role in the treatment and prognosis of the patient [45]. It has been reported that high caries risk patients are predisposed to receive more preventive and/or restorative measures and frequent recalls [46]. However, it has not been clear to what extent such treatments have been prescribed to patients with different caries risk or if the dentists have taken individual patient risk factors into consideration during their routine daily treatment planning.

Finally, this thesis examined how individual patient risk factors were associated with non-operative and operative treatment decisions in a Dental Practice-Based Research Network in The Netherlands.

Aims of the PhD research

The aims of this PhD thesis were:

1 Conduct a critical evaluation regarding the clinical relevance of accuracy studies on the visual and radiographic methods for secondary caries detection, and other aspects, with a systematic literature review *(Chapter 2)*;

2 Explore the contribution of a laboratorial training on the undergraduate's learning process about diagnosis and management of restorations in a controlled randomized study *(Chapter 3)*;

3 Investigate the validity of assessment of intraoral digital photography in the evaluation of dental restorations *(Chapter 4)*;

4 Compare decision-making based on bitewing analysis of restored proximal surfaces by General Dental Practitioners (GDPs) with diagnosis and clinical decisions made by experts in cariology and restorative dentistry, in a practice-based study *(Chapter 5)*;

5 Investigate how individual patient risk factors impact on non-operative and operative treatment decisions in a Dental Practice-Based Research Network in The Netherlands. *(Chapter 6)*.

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CHAPTER 2

Clinical relevance of studies on the visual and radiographic methods for detecting secondary caries lesions – A systematic review

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Abstract

Objective Accuracy studies should associate the diagnostic criteria and outcomes collected to the treatment decision for patients to be considered clinically relevant. This systematic review performed a critical evaluation of the clinical relevance of accuracy studies on the visual and radiographic methods for secondary caries detection, and other aspects.

Source The search was conducted in PubMed, SCOPUS and ISI Web of knowledge databases. Study selection: Accuracy studies assessing clinical and/or radiographic method for evaluation of secondary caries were included. The systematization of the diagnostic criteria, lesion activity assessment and differential diagnosis of secondary caries from factors that can lead to misinterpretations were assessed. Clinical relevance was evaluated by the report of aspects related to: link to treatment decision, evaluation of patient-centered outcomes, establishment of thresholds for non-operative and operative treatment, lesion activity assessment, and reference method. Risk of bias was also assessed. A descriptive analysis was performed.

Data Following eligibility criteria, 19 articles of the 3089 searched were reviewed. Different diagnostic criteria were reported, mainly for the visual inspection. The use of a standardized diagnostic system, lesion activity assessment and differential diagnosis were described by a limited number of studies. Approximately half of the studies reported association of diagnosis and treatment. Enamel lesions were evaluated radiographically in 28.6% of studies, and visually in 69.2%. Visual diagnosis was more relevant in relation to the operative treatment decision. Patient-centered outcomes were not investigated.

Conclusion The majority of studies fails to present clinical relevance and report of patient-centered outcomes.
PROSPERO registration number: CRD42017069977.

Clinical significance
This review highlights the need for improvement of visual and radiographic diagnostic criteria used in the detection of secondary caries to avoid overtreatment and ensure the best treatment for the patient.

2.1 | Introduction

Although studies have evaluated the aspects related to the accuracy of methods for secondary caries detection [1–3], which was also recently summarized in a systematic review [4], few seem to concern about the clinical relevance of the diagnostic criteria used. At the best of our knowledge, only one study based on a simulation model approached this issue in an elegant manner, addressing the clinical implications of the diagnosis based on different criteria and thresholds to the treatment decision [5]. So, the present study proposes the evaluation of accuracy studies investigating secondary caries detection, and if they relate the diagnostic criteria and outcomes collected with the decision that would be made in the clinic for the patients. This relation is called 'clinical relevance' in this paper [6].

Visual and radiographic inspection are the most commonly used methods for the assessment of secondary caries [1–3]. The presence of marginal ditching, staining, discoloration of the dental tissues and gaps at the tooth restoration interface are unreliable predictors for secondary caries [7–10]. Therefore, visual detection of secondary caries is a challenge for the dentist [11] and may be confused with microleakage, that can be visualized as a line of stain around the restoration, or with residual (arrested) caries, which can show a grey discoloration involving the restoration. On the other hand, radiographic methods underestimate lesion extension, and restoration characteristics as restorative material radiopacity, presence of bond layer or residual caries may also lead to misinterpretation [8,12].

Diagnostic mistakes may result in unnecessary and costly [5] replacement of restorations, with perpetuation of the "restorative death spiral" [13]. Approximately 50-60% of the restorations are replaced due to secondary caries [7]. However, this high proportion of replacement may be partially explained by overtreatment [14], since the rate of restorations failing due to secondary caries in controlled clinical trials is low (2-3%) [15–17]. There is a wide diversity of diagnostic criteria available for the detection of secondary caries, which directly affects the clinical outcome regarding the decision of intervene or not [14]. Thus, the content validity of the criteria used should be investigated [18]. Content validity means the comprehensiveness of a system to measure a clinical phenomenon [19]. And it can be assessed through the study of the systems/criteria description for the detection of caries lesions [18]. It should not be confused with criterion validity, which investigates measures of accuracy (e.g. sensitivity, specificity, positive and negative likelihood ratio). These aspects were already systematically addressed in a previously published review [4].

Although accuracy is an important aspect, the choice of the diagnostic method should not be based solely on the accuracy of the method. While different criteria have been proposed and used for the detection of secondary caries, still it does not seem to be a consistent and valid diagnostic system for this purpose. Thus, it is also important to explore the characteristics of the diagnostic criteria reported to find the most appropriate

clinical approach for secondary caries detection. Based on this, and in the fact that few studies seem to correlate the diagnostic criteria used with the impact in the treatment decision, the aim of this systematic review was to conduct a critical evaluation regarding the content validity of the diagnostic criteria and the clinical relevance of accuracy studies on the visual and radiographic methods for secondary caries detection.

2.2 | Materials and methods

2.2.1 | Protocol

This systematic review aimed to answer the question: What is the clinical relevance of studies on the accuracy of visual and radiographic methods to evaluate caries around restorations? The protocol for this systematic review was registered at the International Prospective Register of Systematic Reviews platform (PROSPERO) (number: CRD42017069977). The report of this study followed recommendations of the PRISMA statement [20]. The PRISMA checklist is available in supplemental material (Appendix Table 1).

2.2.2 | Search

The search strategy was performed in May 4, 2017, and included databases Pubmed/ Medline, Scopus and ISI Web of Knowledge. The construction of the strategy was carried out for Pubmed, based on the interaction of the following terms related to the detection methods and clinical condition under investigation (controlled vocabulary and free terms): Radiography, "Visual Inspection" and "Secondary Caries" (Appendix Table 2 in supplemental material). Then, the strategy was adapted to the other databases.

2.2.3 | Eligibility criteria

Types of studies: *In vivo* and *in vitro* studies related to the accuracy of visual and/or radiographic methods for evaluation of secondary caries were included in the review. No date or language restriction was applied.

Types of teeth: Primary and permanent teeth with restorations.

Index tests: The visual and/or radiographic methods were assessed.

Target condition: It included studies investigating caries around restorations.

Inclusion criteria: Only studies presenting data related to sensitivity and specificity, performed in teeth with natural carious lesions were considered.

Exclusion criteria: Studies not reporting diagnostic criteria were excluded. Studies evaluating sealants, radicular caries lesions and residual caries were not included. Lack of access to the full-text study after attempting to contact the author also resulted in study exclusion.

2.2.4 | Study selection

The studies collected from all databases were cross-checked for the exclusion of duplicates. Titles and abstracts were screened independently by two reviewers (C.S and T.G), according to the study main characteristics of interest, with further analysis of the full text. Each reviewer forwarded the studies for inclusion and exclusion, according to eligibility criteria (kappa value: 0.93). Articles with different opinions were discussed among reviewers until a consensus was established. A third reviewer (M.S.C) was consulted when necessary.

2.2.5 | Data collection process

The following data were extracted and recorded in a standard form (Excel, Microsoft, Redmond, WA, USA): data related to the study characteristics (year of publication, study type, index test and reference standard, sample size, tooth and restoration type, condition of restoration, examination protocol, aspects related to differential diagnosis, treatment decision and patient centered-outcomes). The data were extracted by one of the reviewers (C.S.) and re-evaluated by a second reviewer (T.G). Disagreements were discussed, and agreement was reached after consensus between reviewers.

2.2.6 | Content validity assessment

Content validity means the comprehensiveness of a system to measure a clinical phenomenon [19]. To assess the content validity of the criteria, 3 aspects were critically analyzed in the 'Materials and Methods' section of the studies, and registered as 'yes' or 'no' for each study:

Systematization of the criterion: whether the criteria used for the detection of secondary caries lesions were systematized and previously reported in the literature ('yes' or 'no'). Example: Caries Associated with Restorations and Sealants (CARS) criteria [21].

Lesion activity assessment: whether the criteria described by the study evaluate the caries lesion activity ('yes' or 'no'). This aspect was not considered in the assessment of the radiographic criteria. As an example, Lino et al. [3] reported: "Activity of the carious lesion based on visual appearance, local susceptibility to plaque build-up and surface texture". Thus, the study was registered as 'yes' for this aspect.

Differential diagnosis: whether the study inferred the distinction between secondary caries and factors that can lead to misinterpretations ('yes' or 'no'), such as: marginal defects (viz., overhang, gaps), marginal staining, residual caries and presence of radiolucent bonding layer. Such differentiation could be stated in the description of the diagnostic criterion, in the detailed description in the cited reference, or further mentioned throughout the materials and methods section of the included study. Example: Diniz et al. [1] used the CARS (Caries Associated with Restorations and Sealants) criteria, which reports: "Stained margins consistent with non-carious habits and which do not exhibit signs consistent with demineralization should be scored as sound" [21].

2.2.7 | Clinical relevance assessment

The clinical relevance assessment of methods was based on the criteria described by Gimenez et al. [6] and was applied in this review for secondary caries studies. To determine clinical relevance of studies the subsequent strategy was used.

First, the whole article was examined, and the presence of the aspects described below was independently evaluated. Each aspect was reported as 'yes', if present, or 'no', if absent, in a table previously built (Supplemental material: Appendix Tables 3 and 4).

Link to treatment decision: whether the study reported the clinical implications related to the diagnostic criteria used to detect lesions around restorations. The sections material and methods, discussion and conclusions of each study were assessed. Any mention of association between the diagnostic criteria with a treatment decision, operative and/or non-operative, was considered. As an example, Rodrigues et al. [22] reported: "Furthermore, the decision to replace a restoration should also be based on other factors (for example, dietary habits, increased exposure of fluoride, reduction in frequency of fermentable carbohydrate intake and carious activity), because secondary lesions with incipient caries can be controlled if proper cleaning is feasible". So, it was registered as 'yes' for the 'link to treatment decision' aspect.

Patient-centered outcomes: whether the study assessed patient-centered outcome (viz., quality of life, discomfort, dental care-related fear and anxiety).

After this first screening, the specific diagnostic criteria/systems used by each study and described in the 'Materials and Methods' section were assessed, to verify whether the criteria considered thresholds that are related to decision of intervene or not in the clinic. Each study was independently evaluated according to the following aspects, which were assigned as 'yes' or 'no':

Clinical relevance related to non-operative treatment decision: whether the visual criteria described the assessment of initial caries lesions limited to the enamel and/or lesion activity. And whether the radiographic criteria described the assessment of radiolucency limited to the enamel in the diagnosis of the lesions.

Lesion activity assessment: whether the visual criteria included a clear statement of lesion activity evaluation.

Clinical relevance related to operative treatment decision: whether the visual criteria described the assessment of clinical presence of a cavity. The same was applied when the radiographic criteria described the evaluation of radiolucency in dentin compatible with a caries lesion.

Clinical relevance of reference method: in addition, the reference method used by the study was also assessed. It was considered to be clinically relevant when the reference method assessed presence of cavitation and/or lesion activity, which are still the most important measures related to the prognosis of caries lesions and treatment. The evaluation of these characteristics could be performed through visual and/or tactile inspection, clinically or with the aid of microscopy. Studies that did not consider these characteristics or did not use a standard reference method were not considered clinically relevant in this aspect.

2.2.8 | Quality assessment of accuracy studies

The methodological quality of the studies was assessed by the tool QUADAS-2 (Quality Assessment of Diagnostic Accuracy Studies - 2) [23]. Four domains were evaluated to judge the risk of bias and level of concern regarding applicability of the studies:

1 Patient selection: Studies with a non-consecutive or non-random patient sample, with inclusion of only cases of cavitated lesions or exclusion of cases difficult to diagnose were considered as high risk of bias regarding the patient selection.
2 Index test: The index test domain was classified as high risk when the visual and/or radiographic methods were performed with knowledge of the results of the reference standard, and when a threshold was not pre-specified.
3 Reference standard: The domain reference standard was classified as low risk of bias for studies where reference standards were interpreted without awareness of the index test results, as well in cases where the identification of carious tissue was performed by restoration removal and visual and tactile inspection, and/or microscopic analysis.
4 Flow and timing: The flow and time domain was classified as high risk of bias when the reference standard was not applied to all samples, or if all samples were not included in the analysis. Moreover, when an inappropriate interval (more than 1 month) was present between index test and reference standard, which could have been resulted in alterations of the lesion condition, the flow and time domain was classified as high risk too.

Concerns regarding studies applicability were defined as follows:

1 Patient selection: high concern regarding applicability was defined in studies performed *in vitro* and in studies with inclusion of only cavitated lesions.
2 Index test: high concern was expressed when the index test execution, conduction and interpretation were different from the review question. That is, cases in which the visual and radiographic criteria described (index test) evaluated only the presence of non-carious marginal defects without clinically evaluating caries lesions around the restorations, which was only evaluated by standard reference test. For example: visual detection of presence or absence of grey discoloration, without inferring the presence of caries by the index test [10].
3 Reference standard: concern regarding applicability was defined as low when the gold standard identified the presence of lesions around restorations in enamel and/or dentin through the removal of the material and/or clinical examination (visual/tactile), histological/microscopic analysis and/or hardness measurement. Studies that that did not report a reference standard were score as high concern regarding applicability, as also studies assessing the validation of the target condition by radiographic analysis, since the use of only radiographic analysis may imply in the misdiagnosis of demineralization areas already clinically evident, and misinterpretation due to confounders related to the radiographs, such as marginal defects, overhang, residual caries or radiolucent material.

2.2.9 | **Synthesis of results**

Concerning the content validity, the studies were compared in relation to the evaluated aspects (systematization of the criterion, lesion activity assessment and differential diagnosis). Studies that met the highest number of aspects were considered with greater content validity. The aspect 'lesion activity assessment' was not considered in the assessment of the radiographic criteria. In addition, the studies were grouped in the presentation of the results to show the number of studies reporting each aspect related to the clinical relevance, in order to allow an overview about the studies profile. A descriptive analysis of the study findings was performed.

2.3 | **Results**

In total 1428 study titles were found in PubMed, 1009 in Scopus and 652 in ISI Web of Knowledge, resulting in 3089 records identified in the databases, of which 1404 were excluded due to duplication (Figure 1). After inclusion criteria, 50 full-texts were assessed for eligibility, resulting in 19 studies included for data extraction. Eight studies included the assessment by both visual inspection and radiographic methods, 5 articles evaluated only assessment by visual method and 6 only by radiographic method.

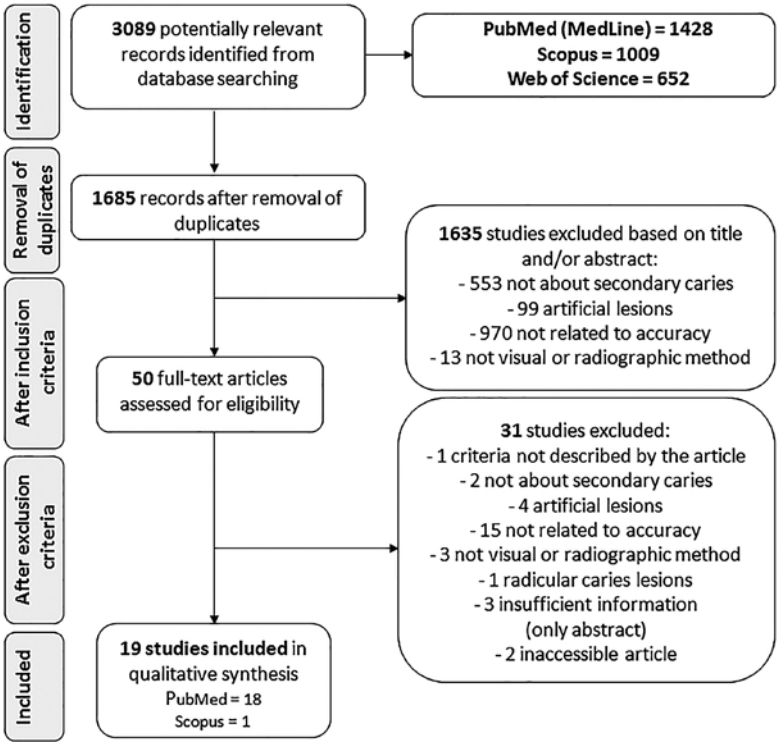

FIGURE 1 | Flow diagram illustrating the search strategy.

The included studies are presented according to the type of study (*in vitro* and *in vivo*) and type of method assessed: *in vitro* (Table 1a) and *in vivo* (Table 1b) studies reporting the visual method, and the radiographic method (Tables 2a and 2b, respectively). The period of studies publication ranged from 1988 to 2016. In general, most of the studies were performed *in vitro*, and proximal surfaces in permanent posterior teeth (molars and premolars) were examined. Amalgam was the most common material, followed by composite.

Studies showed variation between clinical criteria applied, with the use of a standardized system in a limited number of studies assessing visual (46.1%) and radiographic methods (14.3%) (Table 3). Lesion activity was assessed in 15.4% of studies during the visual inspection. The radiographic criteria mentioned in the majority of the studies for the detection of secondary caries were based on the presence of radiolucency around restorations. 53.9% of the included studies assessing the visual method applied some level of differential diagnosis (53.9% marginal defects; 38.4% marginal staining). The presence of marginal defects in the radiographic assessment was evaluated by one study. The distinction between secondary caries and the presence of a radiolucent bonding layer as well as residual caries were not considered in the diagnostic criteria (Figure 2).

TABLE 1a | *In vitro* studies reporting the use of visual method for the detection of secondary caries.

Study	Sample size	Dentition/ Teeth/ Surface	Restoration type/ Material	Condition of restoration	Reference Standard	System and/or Criteria Description	
Diniz 2016 [29]	180 teeth/ 180 sites	Permanent/ Posterior teeth/ Occlusal	Direct/ Composite and amalgam	Intact margins to cavitated margins	Confocal laser scanning microscopy	ICDAS criteria for CARS (summary) [21] (0) sound tooth surface with restoration or sealant (1) first visual change in enamel (2) distinct visual change in enamel/dentin adjacent to a restoration/sealant margin	(3) carious defects of <0.5mm with the signs of code 2 (4) marginal caries in enamel/dentin/ cementum adjacent to a restoration/ sealant with underlying dark shadow from dentin (5) distinct cavity adjacent to a restoration/sealant (6) extensive distinct cavity with visible dentin
Diniz 2016 [1]	110 teeth/136 surfaces	Permanent/ Premolars and molars/ Proximal	Direct/ Amalgam	Intact margins, visual signs of demineralization, or cavitated margins	Restoration removal and visual inspection	ICDAS criteria for CARS. Described previously.	
Lenzi 2016 [2]	42 teeth	Primary/ Molars/ Occlusal	Direct/ Composite	Visually sound to suspicious sites of secondary caries (non-cavitated or cavitated margins)	Restorations removal and visual exam in stereomicroscope	ICDAS criteria for CARS. Described previously.	
Rodrigues 2010 [22]	43 teeth/ 60 surfaces	Permanent/ Molars/ Proximal	Direct/ Composite	Sound and carious	Histological and hardness measurements	Presence of visible marginal color changes surrounding the restoration site, ditches or even cavities.	The following visual scoring system was used: (0) sound surface (1) enamel caries (2) dentin caries
Braga [30]	54 teeth/ 73 sites	Primary/ Molars/ Occlusal	Direct/ Amalgam	Not specified	Restoration removal and caries detector dye	(0) No or slight change in enamel translucency after prolonged air drying (> 5s) (1) Opacity or discoloration hardly visible on wet surface, but distinctly visible after air drying (2) Opacity or discoloration distinctly visible without air drying	(3) Localized enamel breakdown in opaque or discolored enamel (4) Cavitation in opaque or discolored enamel exposing the dentine

Ando 2004 [33]	50 teeth/ 100 sites	Permanent/ Posterior teeth/ Proximal	Direct/ Amalgam	Intact margins, questionable and cavitated margins	Confocal laser scanning microscopy	Demineralization [46]: (0) no or slight change in enamel translucency after prolonged air-drying - 15 seconds (1) opacity or discoloration hardly visible on the wet surface, but distinctly visible after air-drying (2) opacity or discoloration distinctly visible without air-drying (3) localized enamel breakdown in opaque or discolored enamel and/or grayish discoloration from the underlying dentin (4) cavitation in opaque or discolored	enamel exposing the dentin Ditch: (0) no ditches (1) ditches hardly visible (2) ditches visible 0.2 mm (3) ditches visible 10.2 mm Color change: (0) no color change (1) gray or blue discoloration (2) brownish discoloration limited to margin (3) brownish discoloration 0.5 mm from margin (4) brownish discoloration 10.5 mm from margin
Boston 2003 [47]	15 teeth/30 sites	Permanent/ Incisors, canines, premolars and molars	Direct/ Composite	Visually noncarious and possibly carious restoration margins	Microscopic/ staining and visual/ tactile inspection	Classification for enamel and dentin (separeted): 1 = definitely no caries present 2 = problably no caries present 3 = unsure whether or not caries is present	4 = caries is problably present 5 = caries is definitely present Caries was scored as present if a score 4 or 5 was obtained.
Zoellner 2000 [32]	16 teeth	Permanent/ Incisors, canines, premolars and molars/ Cervical	Indirect (Veneer crowns and complete crowns)/ Metal and ceramic	Not specified	Histological	Secondary Caries Index as a modification of root caries index [48]: (1) discoloration at the crown margin because of carious, erosive, or abrasive reasons; no cavitation (2) cavitation, superficial dentin softening; localized to one site, includes maximum of 25% of the margin	(3) cavitation, 2 or more sites, tendency towards circumferential lesion (4) cavitation, deep caries lesion, likely to penetrate the pulp chamber.
Rudolphy 1996 [10]	38 teeth/100 sites	Permanent/ Premolars and molars/ Buccal and lingual	Direct/ Amalgam	None of the teeth showed obvious visible cavitation next to the filling.	Radiographs of the sections	Presence or absense of grey discolouration	
Kidd 1994 [35]	112 teeth/331 restorations	Permanent/ Anterior and posterior teeth	Direct/ Amalgam and composite	Restorations without gross caries	Restoration removal and visual/ tactile inspection	Clinically intact (a good fit with the adjacent tooth), ditched tooth (a visible gap between the filling and the tooth, no caries present)	Cavited outer caries lesion. Colour of the filling margin and of the dentine beneath: stain-free/ stained.

TABLE 1b | *In vivo* studies reporting the use of visual method for the detection of secondary caries.

Study	Sample size	Dentition/ Teeth/ Surface	Restoration type/ Material	Condition of restoration	Reference Standard	System and/or Criteria Description	
Lino 2015 [3]	18 patients/ 87 teeth	Permanent/ Premolars and molars/ Occlusal and/or proximal	Direct/ Composite	With severe dental caries	No reference standard	ICDAS criteria (summary) [21]: (0) sound surface (1) first visual change in the enamel (2) is a distinct visual change in enamel (3) localized enamel breakdown	(4) underlying dentin shadow (5) distinct cavity within visible dentin (6) extensive cavity within visible dentin Activity of the carious lesion based on visual appearance, local susceptibility to plaque build-up and surface texture.
Bamzahim 2005 [49]	21 patients/ 51 teeth/51 sites	Permanent/ Premolars and molars/ Proximal	Direct/ Amalgam	Secondary caries, defective restoration and with esthetic problems	Restoration removal and visual/ tactile inspection	Marginal integrity: clinically intact (restoration closely adapted to the tooth structure), ditching (a visible gap along the margin, no caries discernible)	Caries presence Color of the tooth structure at the margin of the restoration: stain-free/stained
Zoellner 2002 [31]	42 teeth	Primary/ Molars/ Occlusal	Direct/ Composite	Visually sound to suspicious sites of secondary caries (non-cavitated or cavitated margins)	Restorations removal and visual exam in stereomicroscope	Quality of crown margins [50,51]: clinically acceptable unacceptable Caries - Caries free (No discoloration, no cavitation) - Initial caries (Discoloration at the crown margin, white spot lesions, brown spot lesions, no cavitation)	- Suspicious caries (Suspicion of secondary caries, for example, due to wide marginal gap size) - Early caries (cavitation, lesion limited to orthodentin) - Deep caries (cavitation, lesion extends deeply into dentin, likely to include dentin irritation or perforation of the pulp chamber)

TABLE 2a | *In vitro* studies reporting the use of radiographic method for the detection of secondary caries.

Study	Sample size	Dentition/ Teeth/ Surface	Restoration type/ Material	Condition of restoration	Reference Standard	System and/or Criteria Description	
Diniz 2016 [1]	110 teeth/ 136 surfaces	Permanent/ Premolars and molars/ Proximal	Direct/ Amalgam	Intact margins, visual signs of demineralization,or cavitated margins	Restoration removal and visual inspection	Enamel or dentin caries lesions: (0) no radiolucency; (1) radiolucency adjacent to the restoration consistent with enamel caries	(2) radiolucency adjacent to the restoration consistent with dentin caries.
Lenzi 2016 [2]	42 teeth	Primary/ Molars/ Occlusal	Direct/ Composite	Visually sound to suspicious sites of secondary caries (non-cavitated or cavitated margins)	Restorations removal and visual exam in stereomicroscope	Referenced by the article [52] (0) definitively not caries (no radiolucency) (1) probably not caries (if radiolucency, but it did not seem to be related to a defect/ an alteration on cavity walls (physiological resorptions, shadows caused by restorations or radiographic artefacts were considered radiographic signs not related to caries) (2) questionable (radiolucency, but their limits could not permit to assert whether the radiolucency was originated from a defect on cavity walls or was caused by other situations, as described in score 1);	(3) probably caries (if a radiolucency was clearly observed around the restoration, but the examiner could not define the limits by which this radiolucent image was related to a defect on cavity wall) (4) definitely caries (radiolucent image around the restoration, and their limits could be easily defined and were related to the defect margins of a restoration).
Neuhaus 2012 [38]	80 teeth/ 80 sites	Permanent/ Molars/ Proximal (cervical)	Direct/ Amalgam	Visually sound surface or signs of demineralization	Histological and hardness measurements	(0) no radiolucency (1) radiolucency in enamel (2) radiolucency in dentine	
Rodrigues 2010 [22]	43 teeth/ 60 surfaces	Permanent/ Molars/ Proximal	Direct/ Composite	Sound and carious	Histological and hardness measurements	(0) no radiolucency (1) radiolucency on the enamel (2) radiolucency in the dentin	

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Study	Sample size	Dentition/ Teeth/ Surface	Restoration type/ Material	Condition of restoration	Reference Standard	System and/or Criteria Description	
Braga 2010 [30]	54 teeth/ 73 sites	Primary/ Molars/ Occlusal	Direct/ Amalgam	Not specified	Restoration removal and caries detector dye	Referenced by the article [45] (1) definitely not caries (2) probably not caries	(3) questionable (4) probably caries (5) definitely caries
Bamzahim 2004 [53]	66 teeth/ 66 sites	Permanent/ Premolars and molars/ Occlusal and proximal	Direct/ Amalgam and composite	Margins visually sound or with suspect of secondary caries	Restoration removal and visual/ tactile inspection	First criteria: - sound - with secondary caries. Second criteria (level of confidence that a secondary carious lesion was present or not):	(1) definitely not caries (2) probably not caries (3) questionable (4) probably caries (5) definitely caries
Rudolphy 1997 [54]	96 teeth/ 137 surfaces	Permanent/ Premolars and molars/ Proximal	Direct/ Amalgam	Without visible cavitation near the filling	Radiographs of the sections	Caries: radiolucencies and radio-pacities adjacent to the restoration	
Kidd 1994 [35]	112 teeth/ 331 sites	Permanent/ Anterior and posterior teeth	Direct/ Amalgam and composite	Without gross caries	Restoration removal and visual/ tactile inspection	Caries: presence of radioluscency	
Rudolphy 1993 [39]	159 teeth/159 surfaces	Molars/ Occlusal	Direct/ Amalgam	With characteristics indicative for the presence of secondary caries but without visible cavitation	Radiographs of the sections	Caries: radiolucencies and radio-pacities adjacent to the restoration: W (white) - radiopacity D (dark) - radiolucency C (combination) - radiopacity and radiolucency	Regarding extension: small lesions (1-10 mm2), medium lesions (11-20 mm2) large lesions (21 mm2)

TABLE 2b | *In vivo* studies reporting the use of radiographic method for the detection of secondary caries.

Study	Sample size	Dentition/ Teeth/ Surface	Restoration type/ Material	Condition of restoration	Reference Standard	System and/or Criteria Description	
Lino 2015 [3]	18 patients/ 87 teeth	Permanent/ Premolars and molars/ Occlusal and/ or proximal	Direct/ Composite	Severe dental caries	No reference standard	Presence/absence of a radiolucent image underlying the restoration and compatible with dental caries.	
Bamzahim 2005 [49]	21 patients/ 51 teeth/ 51 sites	Permanent/ Premolars and molars/ Proximal	Direct/ Amalgam	Secondary caries, defective restoration and with esthetic problems	Restoration removal and visual/ tactile inspection	First criteria: sound with secondary caries. Second criteria (level of confidence that a secondary carious lesion was present or not):	(1) definitely not caries (2) probably not caries (3) questionable (4) probably caries (5) definitely caries
Zoellner 2002 [31]	100 patients/1332 teeth (820 restorations/ 1640 surfaces)	Permanent/ Proximal	Indirect (Crowns and fixed partial denture abutment)	Not specified	No reference standard	(0) no radiolucency (1) radiolucency limited to outer half of enamel (2) radiolucency extending into inner half of enamel but not crossing the enamel/dentin junction	(3) radiolucency limited to outer half of dentin (4) radiolucency extending into inner half of dentin
Hewlett 1993 [26]	490 patients/ 6285 restorations	Permanent/	Direct/ Amalgam, composite, gold, porcelain	Restorations without and with defects.	Radiographic	Evidence of dental and osseous disease. No attempt was made to distinguish between true secondary (i.e., recurrent) caries and residual caries.	
Gratt 1988 [27]	375 patients/ 200 teeth	Permanent	Direct and indirect/ Amalgam, cast gold, composite, porcelain	Not specified. Only state that used teeth with existing restorations for which removal was planned.	Restoration removal and tactile inspection	Presence of recurrent caries while rating their interpretation according to the following scale: 1 = caries definitely present 2 = caries probably present 3 = I can't tell 4 = caries probably not present 5 = caries definitely not present	

TABLE 3 | Content validity of the visual and radiographic criteria reported by the studies.

	Visual criteria				Radiographic criteria	
Study	**Systematized criterion**	**Lesion activity evaluation**	**Infer differential diagnosis**	**Study**	**Systematized criterion**	**Infer differential diagnosis**
Diniz 2016 [29]	Yes	No	Yes	Diniz 2016 [1]	No	No
Diniz 2016 [1]	Yes	No	Yes	Lenzi 2016 [2]	Yes	Yes
Lenzi 2016 [2]	Yes	No	Yes	Lino 2015 [3]	No	No
Lino 2015 [3]	Yes	Yes	No	Neuhaus 2012 [38]	No	No
Rodrigues 2010 [22]	No	No	No	Rodrigues 2010 [22]	No	No
Braga 2010 [30]	No	No	No	Braga 2010 [30]	Yes	No
Bamzahim 2005 [49]	No	No	Yes	Bamzahim 2005 [49]	No	No
Ando 2004 [33]	Yes	No	Yes	Bamzahim 2004 [53]	No	No
Boston 2003 [47]	No	No	No	Zoellner 2002 [31]	No	No
Zoellner 2002 [31]	No	No	Yes	Gratt 1998 [27]	No	No
Zoellner 2000 [32]	Yes	Yes	No	Rudolphy 1997 [39]	No	No
Rudolphy 1996 [10]	No	No	No	Kidd 1994 [35]	No	No
Kidd 1994 [35]	No	No	Yes	Hewlett 1993 [26]	No	No
				Rudolphy 1993 [39]	No	No

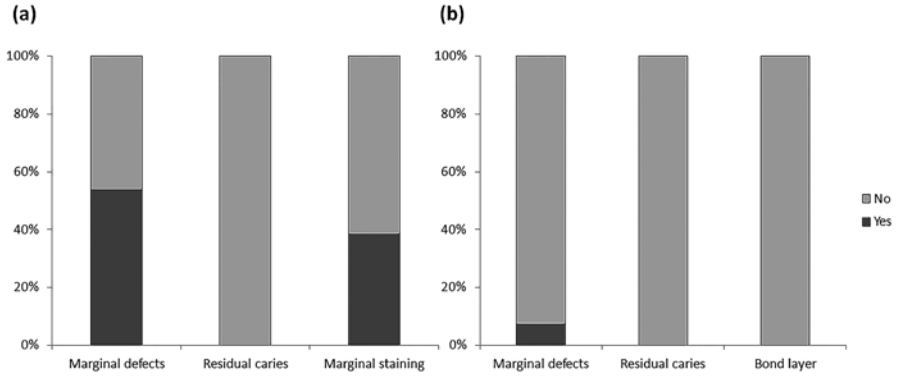

FIGURE 2 | Percentage of differential diagnosis aspects related to secondary caries reported by the (b) visual and (a) radiographic criteria used by the studies.

15.4% of studies reporting the visual method used a systematic diagnostic criterion associated with the evaluation of the lesion activity, and 30.8% a systematized criterion inferring some type of differential diagnosis. The 3 aspects assessed for content validity of visual criteria were not addressed together in a single study. Only one study reporting the radiographic method used a systematized criterion suggesting differential diagnosis (7.1%).

Clinical relevance of the visual and radiographic criteria is displayed in Figure 3. Approximately half of the studies reported association of diagnosis and treatment using visual (46.6%) and radiographic criteria (50%). The presence of lesions restricted to enamel (initial lesions) was evaluated radiographically in 28.6 % of studies, and visually in 69.2%. However, as mentioned before lesion activity was evaluated in a limited number of studies. Visual diagnosis was clinically more relevant in relation to the operative treatment decision (77%) compared to the radiographic diagnosis (28.6%). The majority of studies choose a reference standard not clinically significant (presence of cavitated lesion and/or lesion activity). Patient centered-outcomes were not measured in the studies included. The individual classification of each study is presented in supplementary material (Appendix Tables 3 and 4).

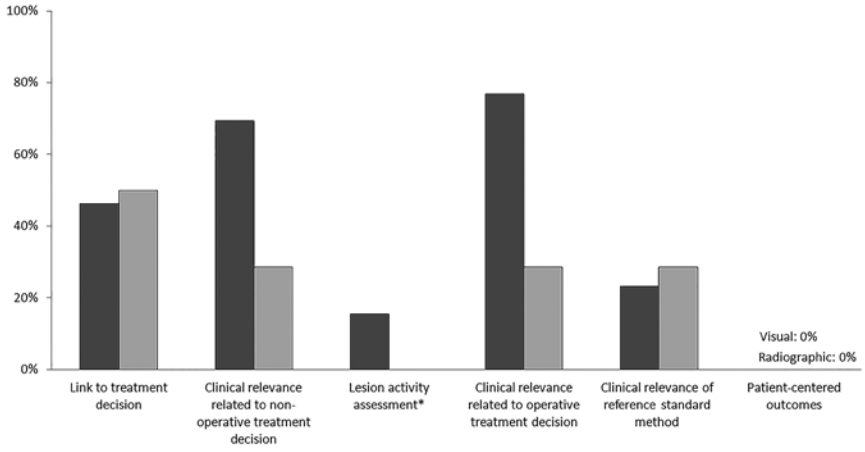

FIGURE 3 | Studies overview regarding clinical relevance of visual (dark bars) and radiographic (bright bars) criteria reported. *Lesion activity assessed only in studies reporting visual criteria.

Figure 4 shows the quality assessment of studies. High risk of bias and concern regarding applicability are expressed for patient selection. Risk for bias was predominantly low for the index test and varied from unclear to high for the reference standard, although low applicability concerns were raised related to these parameters. The detailed classification of each study is available in Table 5 in supplementary material.

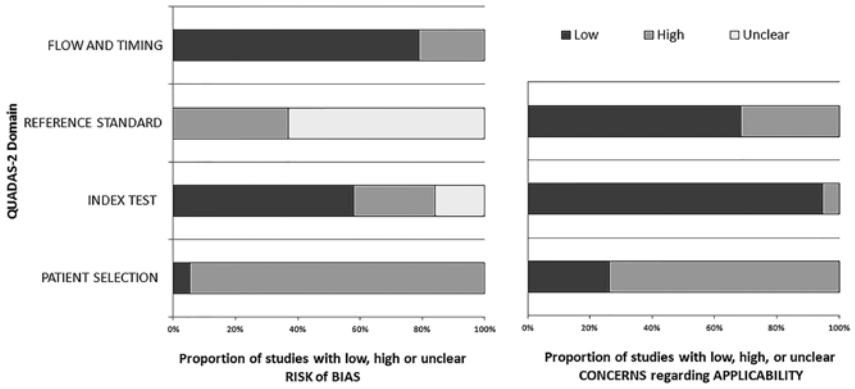

FIGURE 4 | Quality assessment of included articles using the QUADAS-2 tool.

2.4 | **Discussion**

This systematic review examined the content validity of visual and radiographic criteria used to evaluate caries around restorations, because dentists have shown differences in diagnostic and treatment decisions [24,25], which could be due to the criteria available for the detection of secondary caries. In addition, although the accuracy of visual and radiographic methods has been systematically investigated [4], factors related to the treatment decision and patient-centered outcomes should also be considered in the evaluation of diagnostic strategies [6]. Therefore, the results of this study contribute to understand the clinical relevance of accuracy studies regarding the detection of secondary caries. The main findings of this review are that the studies use different criteria, mainly for visual inspection, with lack of clinical relevance. No concern was in fact raised between the applied criteria and patient centered outcomes.

The assessment of secondary caries has been investigated over the last decades, but continues to be target of discussion [8,11,22,26,27] and inconsistency between dentists. Our review shows that different criteria are used for this purpose, which is not helpful for a common understanding of caries-diagnostic process and clinical decision-making [28]. Most of the visual criteria used by the studies assess the severity of the lesion, scoring initial changes in enamel to cavitation into dentin [29–33]. On the other hand, the lesion activity assessment was performed by only 2 studies, in addition to the use of a systematized criterion to assess the severity of the lesion [3,32]. The presence of cavitated lesions that allows biofilm accumulation and lesion activity are significant features related to the diagnosis, as active lesions will require some kind of treatment [34].

Marginal defects and staining around the restoration are not predictive for secondary caries [9,35,36], and are likely the main factors that lead to misinterpretations and possible

overtreatment. For instance, the probe can stick in overhangs suggesting secondary caries [11]. Also, black and brown marginal staining can be misinterpreted as initial lesions and are more often detected in tooth-colored resin restorations than in amalgam restorations [7,37]. Still, these factors were addressed by a limited number of the included studies. The 3 aspects assessed for evaluate the content validity of visual criteria (systematization of the criterion, lesion activity assessment and differential diagnosis) were not addressed associated in none of the included studies. In this sense, the absence of standardization regarding criteria for assessing secondary caries associated with the misdiagnosis of marginal defects as caries lesions reflect the lack of understanding on the factors associated with development of caries lesions around restorations in the clinical practice and are probably associated with excessive and unnecessary interventions on restorations.

The International Caries Detection and Assessment System (ICDAS) includes a list of well-described criteria for Caries Associated with Restorations and Sealants (CARS) [21]. Among the available criteria, CARS seems the more suitable, as not only the diagnosis of the severity of the lesion is described, but also aspects such as stained margins and amalgam shadows not consistent with caries lesions, and the presence or absence of demineralization around a defective restoration are taken into account [21]. However, this system is not able to distinguish between secondary caries and residual caries. Still, it should be used associated with a system for assessing lesion activity.

The radiographic assessment of secondary caries is defined in the majority of studies as the presence of radiolucency [2,3,22,38,39]. Attempts to distinguish confounding factors as marginal defects, residual caries and presence of bond layer were rarely or not reported in the criteria used. Only one study reflected greater content validity of the radiographic diagnostic criteria, reporting the use of a systematized criterion and inferring differential diagnosis between the radiolucent image and other defects [2]. In a previous study, caries around restorations was diagnosed actually in only 14% of restorations showing marginal defects on radiographs [26]. Thus, defective restoration is a poor indicator of radiographic evidence of secondary caries. In addition, the lack of radiopacity of current adhesive systems, especially when applied in a thick layer, might show up as secondary caries, leading clinicians to false positive diagnosis, with faulty replacement decision [12,40]. Moreover, residual caries may also appear as a radiolucent area, leading dentists to intervene in clinically acceptable restorations [8,41], which becomes even more important as modern caries removal techniques recommend leaving carious tissue in deeper cavities [42], that may show a grey and undermining discoloration next to a restoration, which may be misdiagnosed as secondary caries [8]. Therefore, teeth with uncertainty in the diagnosis should be monitored until further clinical or radiographic changes are supporting a better treatment decision [40]. The restoration replacement should be the last alternative instead of the often proclaimed advice: 'in doubt, take it out' [14].

In this review, approximately half of the studies discussed and related in some level the diagnosis to a treatment decision, but the majority of studies failed to use clinically relevant criteria. Regarding visual criteria, severity of the lesion (presence of cavitation) was normally reported, but lack of lesion activity assessment was found, although it has to be mentioned that lesion activity is difficult to determine from *in vitro* studies on extracted teeth. However, lesion activity influences the decision for operative or non-operative treatment [34,43].

Radiographic criteria showed low clinical relevance for a non-operative and operative treatment decision, mainly due to poorly reporting on the lesion threshold in enamel and dentin by the studies. In addition, only one study mentioned the assessment in different stages of progression (outer half and into inner of enamel/dentin) [31], similar to primary caries detection. Also, for both methods, the reference standard was normally not based on lesion activity and presence of cavitation, that are most important for determining the prognosis of therapies [34].

In the era of minimally invasive operative dentistry, the replacement of restorations should be preferably the last alternative for patients with a defective restoration, based on the available evidence for monitoring, refurbishment and repair of restorations [14]. Patient-centered outcomes were not investigated by the studies, which illustrates the lack of concern of diagnostics methods described in the literature and improvement of patients' oral health [6,28]. For secondary caries, diagnostic criteria should reflect the best options for management based on the presence of cavitation and lesion activity, ensuring the best health outcome for the patient [28].

The majority of included studies showed heterogeneity in design. High risk of bias was detected in the patient selection as most studies did not include the sample (teeth or patients) consecutively or randomly. Moreover, high concern was raised regarding applicability as most of the evidence was based on cross-sectional studies performed *in vitro*. *In vitro* findings have several limitations compared to real clinical situations especially regarding activity of a lesion. Low risk of bias was verified for the use of index text in most of studies, with interpretation without previous knowledge of the reference standard and use of pre-specified thresholds. For many studies, the risk of bias was unclear in the performance of the reference standard due to inadequate reporting, probably performed without the use of standardized guidelines [44]. Nevertheless, concerns regarding applicability were low for reference standard and index test.

Finally, few and heterogeneous studies were included in this review, which limits the findings of this study. Also, no statistical analysis was performed since data related to the accuracy of the methods has already been published [4]. On the other hand, the aim of this review was to investigate the content validity of the criteria used, which does not require statistical analysis [18]. Future research should focus on assessment of secondary caries

detection strategies and outcomes related to oral health in adults, following the model of an ongoing randomized controlled trial on radiographic examination on diagnosis and treatment decision of caries lesions in primary teeth [45]. The evaluation of benefits for the patients is fundamental to define the usefulness of visual and radiographic criteria.

2.5 | Conclusions

In conclusion, the majority of studies show lack of clinical relevance and no study evaluated patient-centered outcomes. Moreover, substantial variability was observed in the criteria used for the detection of secondary caries. This review highlights the need for improvement and standardization of visual and radiographic diagnostic criteria based on currently scientific knowledge regarding the detection of secondary caries. In that respect, also effects related to modern caries removal techniques, leaving behind mineralized and discolored tissue should be taken into account, mainly to avoid overtreatment and ensure the best treatment for the patient.

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Appendix

TABLE 1 | PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) checklist.

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	25
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	No
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	27
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	28
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	28
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	28
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	28
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	Supplemental material (Table 2)
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	29
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	29
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	29
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	31
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	29 and 30
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I2) for each meta-analysis.	32

Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	31
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	No
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	32 and 33
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	33 to 41
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	41 and 42
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	33 to 41
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	(no meta-analysis)
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	41 to 42
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	No
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	42 to 45
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	44 and 45
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	45
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	45

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

TABLE 2 | PubMed search strategy.

	Controlled vocabulary and free terms
Caries detection method	((((“Radiography”[Mesh] OR “Radiography” OR “Radiography, Dental”[Mesh] OR “Radiography, Dental” OR “Dental Radiography” OR “Diagnostic X-Ray” OR “Diagnostic X Ray” OR “Diagnostic X-Rays” OR “X-Rays, Diagnostic” OR “X-Ray, Diagnostic” OR “X Ray, Diagnostic”)))
	OR
	((“Visual Inspection” OR “Visual Examination” OR “Visual” OR “Clinical” OR “Clinic” OR “Exams” OR “Examination” OR “Examinations” OR “Inspection”)))
	AND
Clinical situation	((“Secondary Caries” OR “Dental Secondary Caries” OR “Recurrent Caries” OR “Caries Around Restoration” OR “Residual Caries”))

TABLE 3 | Classification regarding clinical relevance of studies reporting visual criteria.

Study	Database	Study type	Is the lesion activity considered?	Whether the criteria distinguishes marginal defects from secondary caries	Whether the criteria distinguishes marginal staining from secondary caries	Whether the criteria mentions differential diagnosis of residual caries	Differential diagnosis from bond layer	Link to treatment decision	Clinical relevance related to non-operative treatment decision	Clinical relevance related to operative treatment decision	Clinical relevance of reference standard method	Patient-centered outcomes
Diniz 2016 [29]	PUBMED	In vitro	No	Yes	Yes	No	Not applied	No	Yes	Yes	No	No
Diniz 2016 [1]	PUBMED	In vitro	No	Yes	Yes	No	Not applied	No	Yes	Yes	No	No
Lenzi 2016 [2]	PUBMED	In vitro	No	Yes	Yes	No	Not applied	No	Yes	Yes	No	No
Lino 2015 [3]	PUBMED	In vivo	Yes	No	No	No	Not applied	Yes	Yes	Yes	without gold standard	No
Rodrigues 2010 [22]	PUBMED	In vitro	No	No	No	No	Not applied	Yes	Yes	Yes	No	No
Braga 2010 [30]	PUBMED	In vitro	No	No	No	No	Not applied	No	Yes	Yes	No	No
Bamzahim 2005 [49]	PUBMED	In vivo	No	Yes	No	No	Not applied	No	No	No	lesion activity	No
Ando 2004 [33]	SCOPUS	In vitro	No	Yes	Yes	No	Not applied	No	Yes	Yes	No	No
Boston 2003 [47]	PUBMED	In vitro	No	No	No	No	Not applied	No	No	No	lesion activity and presence of cavity	No
Zoellner 2002 [31]	PUBMED	In vivo	No	Yes	No	No	Not applied	Yes	Yes	Yes	without gold standard	No
Zoellner 2000 [32]	PUBMED	In vitro	Yes	No	No	No	Not applied	Yes	Yes	Yes	No	No
Rudolphy 1996 [55]	PUBMED	In vitro	No	No	No	No	Not applied	Yes	No	No	No	No
Kidd 1994 [35]	PUBMED	In vitro	No	Yes	Yes	No	Not applied	Yes	No	Yes	lesion activity	No

TABLE 4 | Classification regarding clinical relevance of studies reporting radiographic criteria.

Study	Database	Study type	Is the lesion activity considered?	Whether the criteria distinguishes marginal defects from secondary caries	Whether the criterion distinguishes marginal staining from secondary caries	Whether the criteria mentions differential diagnosis of residual caries	Differential diagnosis from bond layer	Link to treatment decision	Clinical relevance related to non-operative treatment decision	Clinical relevance related to operative treatment decision	Clinical relevance of reference standard method	Patient-centered outcomes
Diniz 2016 [1]	PUBMED	in vitro	Not applied	No	Not applied	No	No	No	Yes	Yes	No	No
Lenzi 2016 [2]	PUBMED	in vitro	Not applied	Yes	Not applied	No	No	No	No	No	No	No
Lino 2015 [3]	PUBMED	in vivo	Not applied	No	Not applied	No	No	Yes	No	No	without gold standard	No
Neuhaus 2012 [38]	PUBMED	in vitro	Not applied	No	Not applied	No	No	Yes	Yes	Yes	No	No
Rodrigues 2010 [22]	PUBMED	in vitro	Not applied	No	Not applied	No	No	Yes	Yes	Yes	No	No
Braga 2010 [30]	PUBMED	in vitro	Not applied	No	Not applied	No	No	No	No	No	No	No
Bamzahim 2005 [49]	PUBMED	in vivo	Not applied	No	Not applied	No	No	No	No	No	lesion activity	No
Bamzahim 2004 [53]	PUBMED	in vitro	Not applied	No	Not applied	No	No	No	No	No	lesion activity	No
Zoellner 2002 [31]	PUBMED	in vivo	Not applied	No	Not applied	No	No	Yes	Yes	Yes	without gold standard	No
Rudolphy 1997 [54]	PUBMED	in vitro	Not applied	No	Not applied	No	No	No	No	No	No	No
Kidd 1994 [35]	PUBMED	in vitro	Not applied	No	Not applied	No	No	Yes	No	No	lesion activity	No
Hewlett 1993 [26]	PUBMED	in vivo	Not applied	No	Not applied	No	No	Yes	No	No	No	No
Rudolphy 1993 [39]	PUBMED	in vitro	Not applied	No	Not applied	No	No	No	No	No	No	No
Gratt 1998 [27]	PUBMED	in vivo	Not applied	No	Not applied	No	No	Yes	No	No	lesion activity	No

TABLE 5 | Quality assessment of studies of diagnostic accuracy (QUADAS-2).

Study	RISK OF BIAS				APPLICABILITY CONCERNS		
	PATIENT SELECTION	INDEX TEST	REFERENCE STANDARD	FLOW AND TIMING	PATIENT SELECTION	INDEX TEST	REFERENCE STANDARD
Diniz 2016 [29]	☹	☺	?	☺	☹	☺	☺
Diniz 2016 [1]	☹	☺	?	☺	☹	☺	☺
Lenzi 2016 [2]	☹	☺	?	☺	☹	☺	☺
Lino 2015 [3]	☹	☺	☹	☹	☺	☺	☹
Neuhaus 2012 [38]	☹	☺	?	☺	☹	☺	☺
Rodrigues 2010 [22]	☹	☺	?	☺	☹	☺	☺
Braga 2010 [30]	☹	☺	☹	☺	☹	☺	☺
Bamzahim 2005 [49]	☹	?	?	☺	☺	☺	☺
Ando 2004 [33]	☹	☺	?	☺	☹	☺	☺
Bamzahim 2004 [53]	☹	?	?	☺	☹	☺	☺
Boston 2003 [47]	☹	☺	?	☺	☹	☺	☺
Zoellner 2002 [31]	☺	☺	☹	☹	☺	☺	☹
Zoellner 2000 [32]	☹	☺	?	☺	☹	☺	☺
Rudolphy 1997 [54]	☹	?	☹	☹	☹	☺	☹
Rudolphy 1996 [55]	☹	☹	☹	☺	☹	☹	☹
Kidd 1994 [35]	☹	☹	?	☺	☹	☺	☺
Hewlett 1993 [26]	☹	☹	☹	☺	☺	☺	☹
Rudolphy 1993 [39]	☹	☹	☹	☺	☹	☺	☹
Gratt 1988 [27]	☹	☹	?	☹	☺	☺	☺

☺ Low Risk ☹ High Risk ? Unclear Risk

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3

CHAPTER 3

Impact of a diagnostic workshop on undergraduate teaching-learning process for the diagnosis and management of tooth restorations – a randomized controlled study

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Abstract

Objective The aim of this study was to investigate the impact of a diagnostic workshop on undergraduate teaching–learning process for the diagnosis and management of tooth restorations.

Methods The first stage of the study was a randomized controlled study with two parallel groups: lecture (L) and lecture coupled with a diagnostic workshop (LW). A pool of cases of tooth restorations including secondary caries and marginal defects was used for training. Theoretical knowledge, perception about the activity, and practical abilities were evaluated. The second stage of the study assessed students' theoretical knowledge retention 6 months following intervention. All students included in the first stage of the study were exposed to LW. Hence, a new control group of students not exposed to LW was selected. One-way analysis of variance, Fisher's exact test, Kruskall–Wallis test, and multilevel regression analysis were used as part of statistical analysis.

Results The LW group had greater scores for the assignment of lesion severity and activity, presence of marginal defect, and treatment indication than the L group ($p < 0.05$). Multilevel regression analysis showed a positive impact of the workshop diagnosis in the correct assessment of lesion activity ($p = 0.03$). There was no statistical difference between the LW and L groups in students' perception of the activity. The LW group showed greater knowledge retention after 6 months than the L group ($p = 0.027$).

Conclusion Lecture coupled with diagnostic workshop improved students' practical skills of diagnosis restorations, and knowledge retention in the 6 months following intervention.

3.1 | Introduction

Secondary caries is a significant clinical problem, often related as the main reason for the replacement of tooth restorations in dental practice [1,2]. It is characterized as a carious lesion adjacent to the restoration [3], and may develop as an "external lesion" on the dental surface near the restoration, similar to the primary caries, and/or as a wall lesion, at the interface of the restoration and cavity wall [4]. The detection of carious lesions is the basis for the treatment decision and directly impacts longevity of restorations, cost of dental procedures, and clinical time [5]. Some clinical features are associated with secondary caries, such as presence of gaps at the tooth–restoration interface, opacity of surrounding dental tissues, and marginal staining [6], may be mistakenly interpreted as carious lesions, especially when located in difficult-to-access proximal areas.

There is wide variation among dentists and lack of consistency [7,8] in diagnostic criteria used in clinical practice [9], which justifies the search for alternatives to improve quality of diagnosis and evaluation of restorations. Education and level of training are likely the main factors affecting clinical decision making [7,10] and dentists must develop during their diagnosis competence according to patient data collection, signs, and symptoms [11]. However, pedagogy in preparing students for daily clinical practice is often based on theoretical lectures [12], presenting with important limitations such as lack of development of critical thinking and problem-solving abilities [13]. Practical training in detection and management of secondary caries [14] could be an alternative tool for improving dentist and undergraduate student competencies. Active learning approaches such as problem-based learning, case studies, and practical training have been shown to be more successful than the traditional model, providing a dynamic and engaging experience for dental students [15–18].

Practical training would ideally use human teeth to mimic clinical work [19]. However, human-extracted teeth with real cases of secondary caries progression is difficult to obtain, and thus other alternatives must be used in the teaching process. Methodologies for artificial secondary carious lesions development have already been published [20,21], and these methods could be used to model lesions at different stages of pathology associated to restored human teeth. *In vitro* biofilm models [22,23] are useful to develop these lesions as they simulate the oral environment exposing restored teeth to sucrose under controlled conditions [24]. This model is capable of producing enamel and dentine demineralization around restorations [20].

There is a lack of controlled studies to assess different methods for teaching dental students on critical clinical procedures. New teaching tools, such as assessment of secondary caries or evaluation of restorations could improve learning and knowledge retention in these students. Therefore, this study's aim was to investigate the benefits of using a diagnostic workshop with cases created *in vitro* in the teaching-learning process directed to dental undergraduate students. In addition, we aimed to test knowledge

retention over a 6-month period to compliment the first aim. We hypothesized that additional practical training associated with lecture would have a positive effect on the performance of dental students in the clinical assessment of restorations.

3.2 | Materials and methods

3.2.1 | Study design

This study was conducted in two stages. The first stage was a controlled design study, characterized by a randomized distribution of students into two parallel groups: lecture only (L), and lecture coupled with diagnostic workshop (LW). The effect of implementing a diagnostic workshop in the teaching–learning process was investigated among undergraduate students. The diagnostic workshop used a pool of restored teeth with secondary carious lesions in different stages of progression created *in vitro*, and restorations with marginal defects. Both groups were evaluated using a theoretical and practical test, followed by a perception evaluation. The outcomes of this first phase were diagnostic performance (theoretical and practical), and students' perceptions.

In the second stage, after 6 months, a questionnaire for knowledge-retention assessment was applied to all students regardless of their initial allocation. For ethical and educational reasons, following the first phase, students in the lecture only group were eventually exposed to the diagnostic workshop. A control group was selected among students enrolled in other classes to which the workshop methodology had not yet been offered. Consequently, the second stage is characterized by a controlled, nonrandomized design and the outcome variable was knowledge retention. Ethical approval was granted by the local Ethics Committee (protocol No. 1.625.236/2016).

3.2.2 | Steps before interventions

a) Preparation of a bank of restored teeth in different conditions

One hundred and fifty-seven human teeth (100 healthy, 25 decayed, and 32 restored teeth) were obtained from the Teeth Bank of the University of Western Santa Catarina (UNOESC/ Santa Catarina – Brazil). Clinical situations were created artificially with healthy and decayed teeth, or were used as collected (restored teeth), to build a bank of restored teeth with different conditions from which teeth could be selected for educational activities.

Conditions created in vitro
Five types of teeth/restorations were prepared: premolar/class II, premolar/class V, molar/ class II, molar/class V and incisor/class IV. Six conditions were simulated *in vitro*: initial white spot lesions, advanced white spot lesions at the margin; dentin lesions associated

with the presence of some marginal gap; marginal staining, lack of marginal adaptation, and adequate restorations. Twenty-five teeth (five premolars class II, five premolars class V, five molars class II, five molars class V and five incisors class IV) were prepared for each condition, with the exception for the marginal staining group, in which 15 teeth were prepared (three for each type of tooth/class), and adequate restoration group, in which 10 restorations were performed (two for each type of tooth/class). For the creation of all the conditions, healthy teeth were used, with the exception for the group dentin lesions associated with the presence of some marginal gap, for which carious teeth were used.

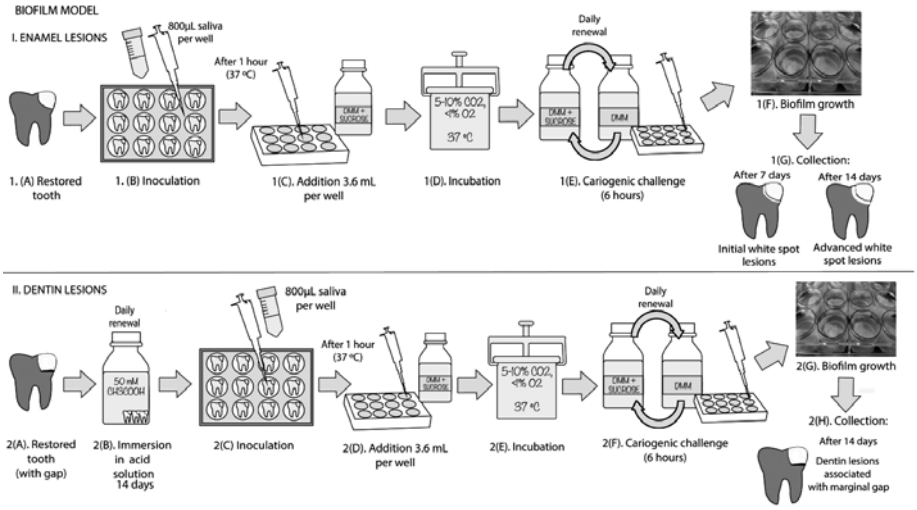

FIGURE 1 | Experimental model for the creation of in vitro carious lesions. 1. Enamel lesions [(A) – Restored tooth, (B) Saliva inoculation, (C) Addition of DMM enriched with sucrose, (D) Incubation in anaerobic jars, (E) Daily renewal of the medium, (F) Biofilm growth on the teeth, (G) Collection of teeth at different times]. 2. Dentin lesions [(A) – Restored tooth with some marginal gap, (B) Demineralization in acid solution, (C) Saliva inoculation, (D) Addition of DMM enriched with sucrose, (E) Incubation in anaerobic jars, (F) Daily renewal of the medium, (G) Biofilm growth on the teeth, (H) Collection of teeth].

Caries around restorations in enamel

Cavity preparations for restorations were performed using diamond burs (1016, 4138). Adper Single Bond 2 (3M ESPE/São Paulo – Brazil) was applied on the cavity surface according to manufacturer's instructions, followed by the insertion of composite resin (Filtek Z350 XT - 3M ESPE/São Paulo - Brazil). Restorations were finished and polished. Secondary carious lesions in enamel were induced using the model previously described by van de Sande et al. [22]. Dental surfaces of teeth were isolated using colorless nail polish, leaving exposed only a 2-mm area around the restoration. The samples were sterilized with gamma irradiation from a cobalt-60 source with particle energies of 1.25 MeV and

4.08 KGy dose (Theratronics, Eldorado 78, Best Theratronic Ltd., Ottawa, Canada). Saliva from a healthy donor abstaining from any oral hygiene method for a period of 24 h and eating 2 h before sample collection was inoculated (800 µL of saliva per well) on teeth restored with resin disposed on 12-well microplates (Figure 1). After 1 h, each well received 3.6 mL of defined mucin medium (DMM) enriched with sucrose. Teeth were incubated in anaerobic jars (Anaerobac/5%–10% CO_2, <1% O_2 - Probac do Brasil Bacteriological products Ltd., Santa Cecília, SP, Brazil) at 37°C and submitted to cariogenic challenge every 6 h. Daily renewal of the DMM medium with and without sucrose was performed. After 7 days of biofilm growth, the group corresponding to the initial white spot lesions was collected, whereas the group of advanced white spot lesions was collected after 14 days.

Caries around restorations in enamel/dentin

For the condition "dentin lesions associated with the presence of some marginal gap," preparations were made leaving intentionally carious tissue behind at the margin [25]. A metal spacer was placed at the tooth–restoration interface for protection of remaining carious tissue and gap simulation. The restorations were placed using the materials previously described according to manufacturer's instructions. After finishing and polishing, teeth were isolated using colorless nail polish, leaving exposed only the gap with the decayed dentin. Then teeth were submitted to the protocol previously used [26], with immersion in a demineralizing solution containing 50-mM CH_3COOH (pH 4.8) at 37.5°C with daily renewal for 14 days until soft decayed dentin was obtained (Figure 1). This protocol was used to reactivate and soften the lesion in dentin. Subsequently, nail polish was removed from a surface of 2-mm area surrounding the gap. After gamma radiation sterilization, teeth were placed in the biofilm model described above for a period of 14 days to complete lesion characterization.

Simulation of defective restorations and marginal staining

Restorations with lack of material or overhang were performed as described before. However, excess or lack of material was left during the insertion of composite resin. Finishing and polishing were not performed in this group of restorations. For the marginal staining group, specimens were immersed in a standardized coffee solution at 37°C for a period of 14 days. The solution was prepared in the proportion of 6 g of coffee (Mellita, Avaré, SP - Brazil) to 100 mL of boiled distilled water [27], renewed daily. After this period, teeth were washed in distilled water and stored in humid conditions until use.

Teeth with natural secondary carious lesions and defective restorations

Thirty-two human teeth with amalgam (n = 28) and resin restorations (n = 4) were used to complement and diversify the diagnostic workshop. The cases were diagnosed by a reference examiner with training and clinical experience in the diagnosis of restorations and classified with the following conditions: adequate restorations (n = 18), lack of marginal adaptation (n = 12), advanced secondary caries in enamel (n = 1) and secondary caries in dentin (n = 1). The allocation of the cases during the activity is described below.

b) Selection of cases for the diagnostic workshop

To test the reliability of the conditions created *in vitro*, a visual inspection was conducted with the aid of a probe and light by the reference examiner. Teeth were examined before and after drying. Characteristics such as the visual and tactile aspect of the surface and location of the lesion were evaluated. This inspection was performed because in laboratory experiments, even under controlled conditions, variation between samples can be found. The examiner analyzed and recorded the diagnosis and treatment indicated for each case.

The best cases were selected by the reference examiner to best simulate the desired clinical situations. A portion of the cases were allocated for the diagnostic workshop and the remainder for a practical test to evaluate student diagnostic performances.

For the diagnostic workshop, three subsamples of 35 cases with the same composition were organized, because the LW group would be divided in three subgroups. The number of teeth selected in the total for each subsample was based on the time available for manipulation and discussion of cases, to allow the manipulation of the cases available per group by all students of the group during the diagnostic workshop. Each subsample was composed by four initial enamel lesions, six advanced white spot lesions, four dentin lesions associated with the presence of some gap, four cases with marginal staining, seven cases with lack of lack of material and overhang and two adequate restorations (Figure 2). In addition, each sample was complemented with three cases of lack of marginal adaptation and five cases of adequate amalgam restorations obtained from the group of cases not artificially created.

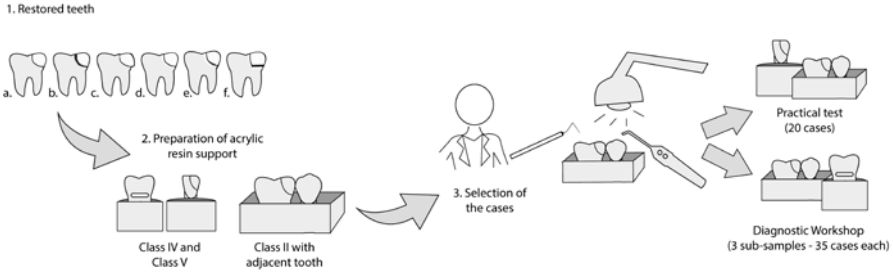

FIGURE 2 | Illustration of prepared cases and selection. (1) Conditions of restored teeth. (a) Adequate restoration. (b) Marginal staining. (c) Lack of marginal adaptation. (d) Initial white spot lesion. (e) Advanced white spot lesion. (f) Dentin lesions associated with the presence of gap. (2) Positioning of the teeth on supports. (3) Selection by a reference examiner.

In addition, 20 restored teeth (12 artificially created and eight not) were selected from the large sample to be used in the practical test: five advanced enamel lesions, three lesions in dentin, seven lack of marginal adaptation, two marginal staining, and three adequate restorations.

3.2.3 | **Participants, interventions, and assessments**

Sample size calculation

Sample size was estimated on the basis of data collected from a previously published study [26]. This study evaluated the skills of the students who participated in two educational methods (traditional lecture and lecture, plus a live demonstration of artificial carious tissue removal) according to the outcome of artificial carious tissue removal, assessed by measuring the residual artificial carious dentine layer (in micrometers) of the teeth assessed by the students. For the sample size calculation, independent samples t-tests were performed between individuals of both the groups (L and LW) at a rate of 1:1 to be able to reject the null hypothesis that the means of the groups are equal, with probability of 80%. The type-I error probability associated with the test of this null hypothesis was 5%. The standard deviation retrieved from the mentioned study was 130 µm, and the difference in the mean was 200 µm for residual decayed dentine in incisal area for different groups (lecture and demonstration). Therefore, eight subjects were included in each group. Considering that the study is developed for the classroom, all students in the class were invited to participate. In the end, 40 volunteers (all eligible students) were included in the study, with each group consisting of 20 volunteers each. Statistical analyses was performed with PS Power and Sample Size Program software, version 3.0.43 [28].

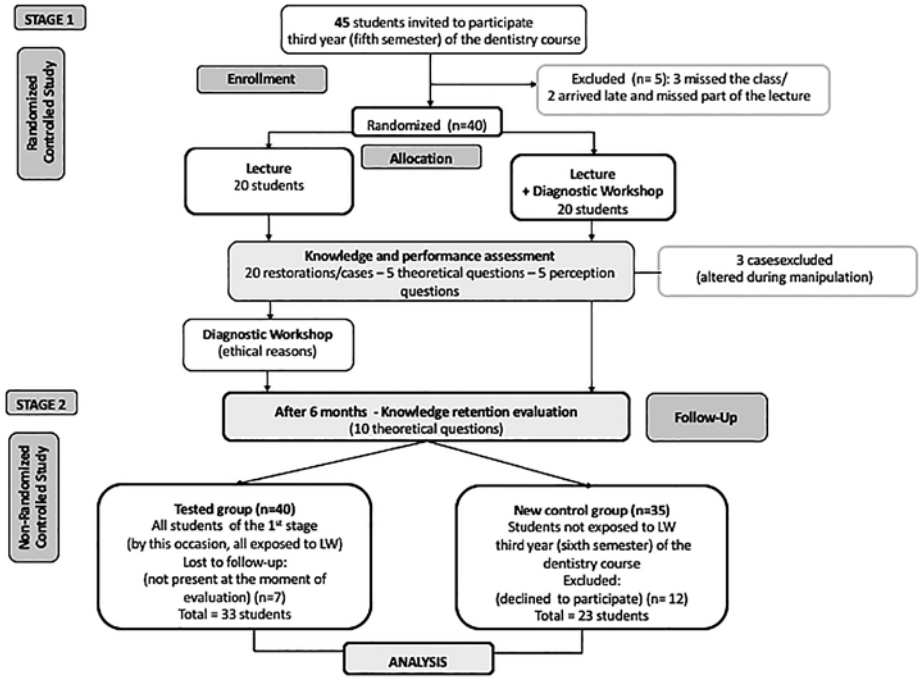

FIGURE 3 | Flow chart according to the student's enrolment.

Participants

The flow chart showing the student enrolment is displayed in Figure 3. Students attending to the discipline of cariology and restorative dentistry in the third year of the dentistry course were considered eligible for the study. At this stage, the students had had contact with the clinic in the previous semester only through of examinations and elaboration of patient treatment plan, without actually executing procedures. This study was performed in the first semester of the third year, and students began their first clinic to which they were responsible for the design and implementation of patient treatment plans. They had 1 day of clinic at the time this educational activity was performed. All participants provided written, informed consent. Students were randomized into two groups (n = 20) using random sequence generated by Microsoft Excel Software (Microsoft Inc., Redmond, WA, USA). Each student was identified with a number between 0-40 in Excel spreadsheets corresponding to the students identification to posterior record of data and statistical analysis preserving the students's identity.

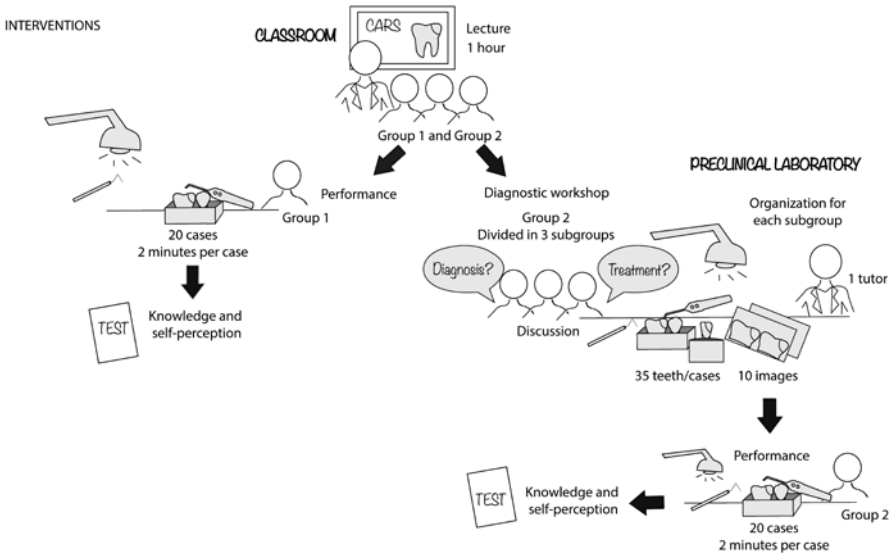

FIGURE 4 | Design of interventions.

Interventions

One group (L) received a lecture whereas the other group (LW) received the same lecture associated to the diagnostic workshop (Figure 4). The 1-h lecture was applied to both groups simultaneously by a professor with extensive experience in the field of cariology. The lecture explained the diagnosis and the decision to intervene on a defective restoration, with emphasis on secondary caries detection according to the "Caries Associated with Restorations or Sealants" (CARS) criteria, of ICCMS (International Caries Classification and Management System) [29].

Immediately after the lecture, the LW group was taken to the preclinical laboratory to perform the diagnostic workshop. The students in the LW group were divided into three subgroups to ensure closer interactions. Each subgroup received 10 images and 35 teeth/cases. One graduate student (tutor) was responsible for supervising each subgroup. The tutors discussed the images together with the teachers and graduate students, after handling the teeth using a probe. The diagnosis and indication for treatment of each case and image were determined. The answers were corrected and doubts were clarified. Both groups were maintained in separate rooms during all phases of the activity following the common lecture. At the end of the lecture, the L group received the knowledge and performance assessment as described below whereas the LW group underwent a diagnostic workshop. Following the diagnostic workshop, the LW group was assessed for knowledge and performance assessment. The students in the L group participated in a new round of the diagnostic workshop after the knowledge assessment so that they would not suffer any kind of educational loss.

Knowledge and performance assessment

The students' knowledge assessment was assessed with a theoretical and practical test. Students' diagnostic performance was assessed with a practical evaluation of 20 cases (teeth) previously selected by examiners. The teeth were individually disposed and examined by the students using artificial illumination, triple syringe (air/water), and ball-point probe. The students received a form where the following aspects should be determined: presence of secondary caries (yes or no); lesion severity (CARS scores per surface); lesion activity (active or inactive), investigating aspects such as enamel opacity, roughness, and dentin hardness to define active or inactive lesions; presence of marginal defects (yes or no), and treatment indication: monitoring (without necessary intervention, follow-up of the restoration over time), nonoperative treatment (conservative treatments as professional topical fluoride application or finishing and polishing of the restoration) or operative treatment (repair or replacement of restorations). The aspects lesion severity and activity were assessed by restored surface; 25 surfaces from 20 teeth were evaluated for these aspects because some restorations had more than a single surface. For the other aspects (presence of secondary caries, presence of marginal defects, and treatment indication) the status of the entire restoration was considered. Students had 2 min to examine each tooth. In the end, the students' responses were compared to those of the reference examiner, and the number of correct answers was registered. The theoretical test was comprised of five questions concerning the diagnosis and treatment, which was elaborated by a group of three lecturers experienced in cariology teaching.

Student's self-perception assessment

A questionnaire based on a previously published scale sensitive to detect fluctuations in state anxiety [30] was used to assess the dental students' self-perception about the activity. The aim was to assess if the students exposed to workshop training felt more enthusiastic and prepared to diagnose restorations in the clinic.

Five questions were asked to the students: (1) whether they felt upset about the activity; (2) whether they felt content (satisfied) about the activity; (3) whether they felt tense about the activity; (4) whether they felt self-confident about their performance; and (5) whether they were self-confident in diagnosing secondary carious lesions following the theoretical class. The four possible answers were absolutely not, little, moderately, and extremely.

Knowledge-retention assessment
The knowledge retention of the undergraduate students was assessed after 6 months by applying a theoretical evaluation, including 10 questions prepared by a group of lecturers experienced in cariology. The questions regarded diagnosis and management of secondary carious lesions. The control group for the knowledge retention was data collected from a class in the following semester in which the methodology was not applied.

3.2.4 | **Statistical analysis**

The knowledge-retention and performance-assessment analyses were based on theoretical answers and five clinical parameters assessed by the students: presence of secondary caries, lesion severity, lesion activity, marginal defects, and treatment indication. For the analysis, the correct answers for each parameter (outcomes) were extracted. The detection of caries using CARS was analyzed as right or wrong answer based on the merged categories [29]: healthy surface (code 0), initial carious lesions (codes 1 and 2), moderate (codes 3 and 4), and extensive carious lesions (codes 5 and 6). Independent comparisons between the groups (L and LW) were determined by one-way analysis of variance. The student's perceptions of the activity were assessed by Fisher's exact test.

In addition, Poisson multilevel regression analysis was performed to examine the influence of variables on student level and evaluation level on the answers. At the student level, the only variable was the group (L or LW) that students were allocated to. At the evaluation level, the independent variables were lesion severity, lesion activity, and restoration type. Crude and adjusted relative risk values with respective 95% confidence intervals and significance level were estimated in a univariate analysis. Multivariate modeling was performed using the forward stepwise strategy. The knowledge-retention analysis between the groups was compared through Kruskal–Wallis test. A statistical package (Stata 13.0, StataCorp, College Station, TX, EUA) was used for all the statistical analysis. The significance level was set at 5%.

3.3 | **Results**

Forty-five students (27 females and 18 males) agreed to participate in the study. Five were excluded because they missed class or part of the lecture, leading to 40 total students taking part in the study. During the performance assessment three cases (teeth) were

altered during manipulation (tooth fracture) and excluded. After 6 months, 33 students underwent knowledge-retention analysis. For the knowledge-retention comparison (control group), 35 students were invited from another class, of which 23 students attended the evaluation.

Diagnostic performance and theoretical evaluation results are shown in Table 1. Greater mean values were observed for the group receiving the diagnostic workshop. The workshop significantly affected the students' ability to determine lesion severity (p = 0.028), carious lesion activity (p = 0.011), presence of marginal defect (p = 0.009), and indication for treatment (p = 0.049). There were no differences in theoretical variables between the groups.

TABLE 1 | Average score (SD) of the diagnostic performance and theoretical knowledge of the groups submitted to the lecture and lecture associated to the diagnostic workshop.

Variable			**p-value**
	Lecture	Lecture + additional training	
Diagnostic performance			
Presence of secondary caries (0 to 20)	11.8 (1.89)	12.9 (1.97)	0.078
ICDAS diagnosis (0 to 25)	12.1 (2.70)	14 (2.56)	0.028*
Lesion activity (0 to 25)	9.65 (3.66)	12.55 (3.19)	0.011*
Presence of marginal defect (0 to 20)	10.8 (2.48)	12.75 (1.99)	0.009*
Treatment indication (0 to 20)	10.5 (2.14)	12.1 (2.81)	0.049*
Theoretical knowledge			
Test (0 to 5)	3.75 (1.29)	3.95 (1.00)	0.587

** Statistically significant (p<0,05; One-way analysis of variance).*
Note: ICDAS categorized according to ICCMS guide [29].

Table 2 shows the multilevel regression models associating the students' performance (correct answers) with factors related to the students (level 1) and evaluation (level 2). In the model, the intervention did not impact students' performance for detecting the presence of secondary caries (p = 0.54), marginal defects (p = 0.07), and treatment decision (p = 0.13). However, students' participating in the workshop performed significantly better on lesion severity by 20%; p = 0.05) and lesion activity (30%; p = 0.006).

TABLE 2 | Poisson multilevel regression analysis of factors related to the answers of students (correct/incorrect) according to the outcome variables.

Variables	Model 0 Crude RR (95%CI)	p-value	Model 1 Adjusted RR (95% CI)	p-value
Outcome: presence of secondary caries				
Level 1 – Students				
Group (ref. Theoretical)				
Workshop	1.09 (0.92-1.30)	0.32	1.09 (0.92-1.30)	0.32
Level 2 – Evaluation				
Lesion activity (ref. Without lesion)				
Initial inactive lesions	0.58 (0.36-0.95)	0.03	0.58 (0.36-0.95)	0.03*
Initial active lesions	0.93 (0.73– 1.18)	0.55	0.93 (0.73– 1.18)	0.55
Advanced active lesions	1.31 (1.02-1.68)	0.04	1.31 (1.02-1.68)	0.04*
Outcome: lesion severity				
Level 1 – Students				
Group (ref. Theoretical)				
Workshop	1.20 (1.0-1.44)	0.05	1.20 (1.0-1.44)	0.05*
Level 2 – Evaluation				
Severity (ref. Without lesion)				
Initial lesions	0.50 (0.39-0.65)	<0.001	0.50 (0.39-0.65)	<0.001*
Advanced lesions	1.14 (0.86-1.51)	0.36	1.14 (0.86-1.51)	0.36
Outcome: lesion activity				
Level 1 – Students				
Group (ref. Theoretical)				
Workshop	1.30 (1.08-1.57)	0.006	1.30 (1.08-1.57)	0.006*
Level 2 – Evaluation				
Lesion activity (ref. Without lesion)				
Initial inactive lesions	0.12 (0.04-0.37)	<0.001	0.12 (0.04-0.37)	<0.001*
Initial active lesions	0.62 (0.49-0.80)	<0.001	0.62 (0.49 – 0.80)	<0.001*
Advanced active lesions	0.76 (0.54-1.06)	0.11	0.76 (0.54-1.06)	0.11
Outcome: presence of marginal defect				
Level 1 - Students				
Group (ref. Theoretical)				
Workshop	1.18 (0.98-1.42)	0.07	1.18 (0.98-1.42)	0.07
Level 2 - Evaluation				
Restoration type (ref. Class I)				
Class II	1.05 (0.87- 1.27)	0.60	1.05 (0.87- 1.27)	0.60
Class V	1.45 (1.02- 2.05)	0.04	1.45 (1.02- 2.05)	0.04*
Outcome: treatment indication				
Level 1 - Students				
Group (ref. Theoretical)				
Workshop	1.15 (0.96-1.39)	0.13	1.15 (0.96-1.39)	0.13
Level 2 - Evaluation				
Restoration type				
Ref. Class I				
Class II	0.69 (0.57-0.83)	<0.001	0.78 (0.64-0.96)	0.02*
Class V	0.94 (0.64-1.37)	0.74	0.94 (0.64-1.39)	0.76
Lesion activity (ref. Without lesion)				
Initial inactive lesions	0.77 (0.50-1.19)	0.24	0.69 (0.44-1.08)	0.10
Initial active lesions	0.47 (0.34-0.65)	<0.001	0.53 (0.38-0.76)	<0.001*
Advanced active lesions	1.33 (1.04-1.71)	0.03	1.34 (1.04-1.72)	0.02*

Note: RR (relative risk), ref. (reference category).
**p-value statistically significant (£0.05).*

Students' perceptions of the activity are illustrated in Figure 5. Although no statistical difference was observed between the L and LW groups in students' self-perception for the different items (being upset: p = 1.0; being satisfied/content : p = 0.235; being tense: p = 0.176; self-confident in their performance: p = 0.451; and self-confidence in knowledge acquired in theoretical class: p = 1.0), we can visually observe some specific trends (Figure 5) in the LW group that could suggest a better overall self-perception related to the activity.

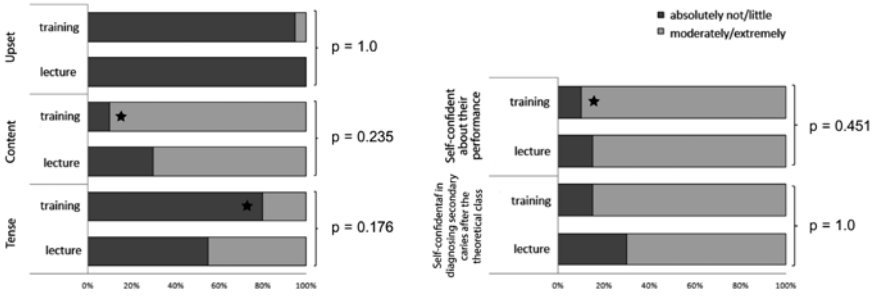

FIGURE 5 | Graphs of students' perception of the activity. Percentage of participant's response regarding how they felt in relation to the activity and according to their self-evaluation of performance. *p-values refers to the comparison in perception between the groups. The symbol indicates some specific trends in LW group.

After 6 months, the group who underwent the training workshop provided 71.9% correct answers compared to 59.2% provided by those in the control group (p = 0.027).

3.4 | **Discussion**

Our main findings showed that although similar performance has been observed for the theoretical knowledge domain for both groups immediately after the interventions, there was an improvement in the students' practical skills to diagnosis restorations by the implementation of training workshop in addition to the lecture; this is in agreement with the results of previous studies [26,31,32].

Two different analyses (comparison of means and multilevel regression analysis) were performed on the basis of the knowledge and performance assessment. The multilevel regression analysis showed a different result from that found in the analysis of the mean scores, with no significant impact of the workshop on the students' performance for the outcome presence of marginal defect and indication of treatment. This may be explained by the sample size calculation based on comparison of means; it is likely that a larger sample size would be needed to show the same differences in the multilevel regression analysis. We also believe that the average of correct responses is likely more discriminatory

than the multilevel regression analysis. On the other hand, multilevel regression analysis allows us to examine which aspects of the educational experience influenced the correct responses from the students. Therefore, we decided to show results in this manuscript.

The LW group showed a higher number of correct answers in the assignment of severity and activity of carious lesions compared to the L group, although similar scores were found in the assessment of the presence of secondary caries. However, the binary assessment (yes/no) of only presence or absence of caries could result in inappropriate interventions [33]. The ability of the student to perform a diagnosis considering/assessing the lesion activity and severity is one of the core competencies required for undergraduate students [11], because correct assessment of lesions results in improvements in the treatment decision [34]. The results from the multilevel regression model reinforce the positive impact of the workshop strategy on the assessment of lesion activity and show a trend ($p = 0.05$) to better performance in the assignment of lesion severity.

The assessment of marginal defects around restorations such as staining, gaps, and overhangs, misdiagnosed as secondary caries [3,35,36], also plays an important role in the management of restorations. Alternatively, the differentiation of these conditions has been made by images; however, it is not always clear for the students what these images clinically represent. Moreover, our results showed higher scores in the detection of marginal defects for the LW group. Correct answers for the presence of marginal defect by students in general were more common in class-V restorations, which may be explained by the facilitated access. Also, for the treatment indication, we observed poorer student performance for class-II restorations, which is usually a difficult assessment because of the proximity of the adjacent tooth. This may also be related to the lack of complementary diagnostic tools during the activity, such as a radiographic exam. The role of other potential diagnostic tools to aid the student in the clinical diagnosis should be investigated in further studies.

In addition, students showed difficulty in diagnosing initial inactive lesions. The discrimination between initial lesions and healthy surfaces is challenging, which may result in greater misclassifications [37]. Yet, correct treatment was better indicated for advanced lesions than for initial lesions. This may be explained by the difficulty of diagnosis, and linked to less conservative decision making, with possible overtreatment of initial lesions because of the lack of clinical experience of students [33,38].

It is suggested that accurate detection of the lesion leads to the accurate choice of treatment [5], which could be one of the reasons why the LW group showed a higher average score in treatment indication. In addition, although this difference was not statistically significant in the multilevel regression model, the LW group had 15% greater success rate than the L group in the treatment assignment, suggesting a tendency of improvement in the treatment decision.

The method used to create lesions was capable to provide artificial caries-like lesions with whitish opaque and rough enamel and soft dentin. This method is feasible for other dental schools to execute and implement. Although it is known that the activity is a clinical and dynamic variable, the induction of secondary carious lesions *in vitro* is a tool for simulate clinical situations, inducing new carious lesions [20], or reactivating pre-existing lesions, because extracted restored teeth with characteristics of active lesions are difficult to find.

In our study, the majority of the students presented a positive perspective in relation to the training [13,32]. A small portion of the training group felt upset, likely because of the increased time and attention required to execute the training in addition the performance and knowledge assessments. On the other hand, students in this group also tended to perceive themselves as more satisfied with the activity and confident with their developed abilities. The satisfaction reflects the feeling of sufficiency, and individual learning needs were met, resulting in a more motivated student.

Students exposed to a new activity for which they had no previous training (lecture group) tended to more often describe themselves as tense. The use of additional methodologies can positively affect the degree of preparation perceived by the students [13]. Although trends were observed, there was no significant difference between the groups. We should consider that this assessment was conducted using a randomized controlled design, wherein students are blind to the alternate option. Thus, lower discrimination could be expected for their preferences [39].

The use of different methodologies in previous research studies appeared to increase knowledge [40,41], which is consistent with the findings in our study where the LW group tended to have greater knowledge retention. Ideally, the control group for knowledge-retention analysis would be the group originally submitted only to the lecture (L group), as to have a naïve measurement 6 months after intervention. However, by the time of the second stage, the L group had already participated in the diagnostic workshop, as we must consider the ethical implications of withholding educational modules from students. To address this, we opted to use as control group a group of students in the next semester, to whom the workshop activity had not been offered. This was an expected limitation of our study, but we cannot be sure that the samples between students across semesters are equivalent samples. The control group scored nearly 60% in correct answers despite not being offered the workshop, reinforcing the value of the theoretical lectures. However, the LW group presented with higher percentage of correct answers (71.9% vs. 59.2%), which suggests that the discussion of cases and clinical application of information actually contributed to the students retention of knowledge over time, resulting in improved teaching–learning process. Therefore, based on our results, the hypothesis of the present study – the improvement of learning and retention with the addition of a practical learning module to theoretical lectures – was confirmed.

The current study suffers from a small sample size and single-center nature of the study, which was performed with one classroom of students and does not allow to explore different contexts [42]. However, a positive point raised is that all students from the classroom were invited to participate with a good response rate, decreasing the selection bias which is common in this type of pedagogical study [43,44]. It is strategic to conduct these relatively smaller studies to analyze the experimental strategies before deploying a larger study, such as multicenter studies, because of the logistical and material challenges of this type of study. The study outcomes were based on the analysis of correct answers by students; that can occur only by chance in some cases, which is a limitation of our study. However, it represents the standard assessment of students' performance still used in the academic environment. Moreover, the restorations were evaluated only by one reference examiner, which could introduce some level of bias to the study but also represents the lecture/instructor perspective when teaching their students. In future studies, one alternative is to use more than one evaluator and to establish a consensus to ensure that different potential clinical judgments can be considered.

The educational/teaching method reported, compared to the traditional lectures has the advantage of allowing dentistry schools to evaluate their teaching procedures academically. Additionally, the curriculum could be improved by employing additional training [12]. However, the cost-effectiveness of conducting such additional training should also be investigated to support employing this type of educational strategy. In addition, the conduction of a multicenter studies to test the applicability of this kind of methodology in other centers and realities seems to be interesting for future perspectives [42].

3.5 | **Conclusion**

There was improvement in the students' practical skill in diagnosis when a practical training workshop was implemented additional to a traditional lecture. In addition, these students had better knowledge retention 6 months after intervention. In conclusion, the employment of a diagnosis workshop has a positive impact in the teaching–learning process related to the diagnosis and management of tooth restorations.

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4

CHAPTER 4

Validation of assessment of intraoral digital photography for evaluation of dental restorations in clinical research

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Abstract

Objectives The aim of this study was to investigate the validity of assessment of intraoral digital photography in the evaluation of dental restorations.

Methods Intraoral photographs of anterior and posterior restorations were classified based on FDI criteria according to the need for intervention: no intervention, repair and replacement. Evaluations were performed by an experienced expert in restorative dentistry (gold standard evaluator) and 3 trained dentists (consensus). The clinical inspection was the reference standard method. The prevalence of failures was explored. Cohen's kappa statistic was used. Validity was accessed by sensitivity, specificity, likelihood ratio and predictives values.

Results Higher prevalence of failed restorations intervention was identified by the intraoral photography (17.7%) in comparison to the clinical evaluation (14.1%). Moderate agreement in the diagnosis of total failures was shown between the methods for the gold standard evaluator (kappa = 0.51) and consensus of evaluators (kappa = 0.53). Gold standard evaluator and consensus showed substantial and moderate agreement for posterior restorations (kappa = 0.61; 0.59), and fair and moderate agreement for anterior restorations (kappa = 0.36; 0.43), respectively. The accuracy was 84.8% in the assessment by intraoral photographs. Sensitivity and specificity values of 87.5% and 89.3% were found.

Conclusions Under the limits of this study, the assessment of digital photography performed by intraoral camera is an indirect diagnostic method valid for the evaluation of dental restorations, mainly in posterior teeth. This method should be employed taking into account the higher detection of defects provided by the images, which are not always clinically relevant.

Clinical significance
The assessment of intraoral digital photography is a valid method for the evaluation of dental restorations. The method provides significant information and it is a potential tool for use in Practice Based Research Network, improving the level of evidence in clinical research.

4.1 | Introduction

Studies on the clinical performance of dental restorations are essential to investigate outcomes related to the diagnosis, treatment and longevity of restorations [1]. The demand for evidence-based dentistry resulted in the increase of clinical studies in the last years [2]. In this context, practice-based studies using data from general dental practice networks (PBRN) emerged and gained a relevant role [3]. This type of study allows the investigation of interventions and associated risk factors in a real-world setting, with access to a representative amount of restorations treated by general practitioners, and to long-term observation periods [4]. On the other hand, these studies are often less standardized in comparison with clinical controlled trials [1, 5]. Practitioners without previous training in diagnosis, treatment and assessment of restorations can incorporate some level of bias in the research [1], since there is still great heterogeneity among dentists in the diagnosis and decision to repair or replace restorations [6, 7]. This may be a reason for the great variation in longevity of dental restorations that is found in practice based studies [8-10].

Different criteria have been developed and used in clinical research to diagnose restorations and establish their quality [11]. The main criteria used are the FDI World Dental Federation [12] and modified US Public Health Service (USPHS)/Ryge criteria [13]. The available criteria, although well described, are complex for the use by the general practitioner in everyday practice [14]. Clinical diagnosis is a subjective process, and therefore susceptible to different interpretations, even among experienced clinicians, depending on whether they are more or less conservative [11]. The use of digital photography in PBRN is an alternative to evaluate the quality of restorations reducing the risk of reporting bias. The purpose is that general dental practitioners take the photograph in their clinical practice and send it to independent investigators for assessment [1].

For caries diagnosis, photographic evaluation showed compatible results with the visual detection method [15-17], and can serve as an important source of information. Likewise, intraoral digital photography has been investigated for use in restorative dentistry, and is reported as a suitable diagnostic tool for dental conditions such as tooth decay [18,19], dental trauma [20], tooth wear [21] and for the assessment of dental sealants and restorations [22-25]. In this context, the intra-oral camera seems to be a promising and viable tool for use in the PBRN [26-28]. The portable device provides fast and easy collection of digital images, allowing the register of the treatment performed by the dentist and subsequent follow-ups [23].

Therefore, the aim of this study was to investigate the validity of assessment of intraoral digital photography in the evaluation of dental restorations. The hypothesis tested was that the assessment of digital photography performed with intraoral camera has similar outcome compared to direct evaluation of restorations.

4.2 | Materials and methods

4.2.1 | Study design

This was a validation study for the assessment of intraoral digital photography in the evaluation of anterior and posterior resin restorations. The photographs were taken with an intraoral camera. Restorations were classified based on FDI criteria according to the need for intervention: (0) no intervention, (1) repair and (2) replacement. Evaluations were performed by an expert in restorative dentistry, with training and extensive experience in the diagnosis of restorations (gold standard evaluator), and by 3 trained dentists (consensus). The clinical inspection was the reference standard method. The main factor under analysis was the validity of assessment of intraoral photographic method for the diagnosis of restorations and decision of treatment.

4.2.2 | Study participants

The present study was performed with a sample of individuals, aged between 18 and 57 years, selected from an ongoing randomized clinical trial (RCT) related to the evaluation of several restorative dentistry outcomes, including clinical performance of materials and restorative techniques. The RCT is held in the School of Dentistry (Federal University of Pelotas, Pelotas, Brazil). The study participants were all adults, having at least one composite restoration placed in anterior or posterior teeth (from 1 up to 5 restored surfaces). The individuals were invited to participate to the study on the RCT follow-up visits. The study was approved by the local Ethics Committee (protocol Nº 1.468.455/2016), and participants have signed a written informed consent.

4.2.3 | Sample Size

Sample size was estimated based on data from a previously published study [29]. Considering a prevalence of 10% of unsatisfactory restorations in the population a desired specificity and sensitivity of 80% for intra-oral digital photography, 80% of power and 5% of confidence level, a total of 165 restorations was required to perform the study. Taking into account that all the patients in the randomized trial follow-up visits were invited to participate and the possibility of exam of more than 1 restoration per patient, at the end 198 restorations were included in the study. The calculation was performed with PS Power and Sample Size Program software, version 3.0.43 [30].

4.2.4 | Clinical examination (reference standard method)

Composite restorations were clinically evaluated by one experienced and trained dentist (gold standard evaluator) (MSC) with dental explorer and mirror, air of a triple syringe and artificial light, according to FDI criteria [12]. Patients were examined in a clinic of Dental

School, with an average of 10 patients per day (20 min for each patient). Teeth were initially cleaned with dental gauze as necessary. The quality of the restorations was based in the following criteria described by FDI: surface roughness, surface and marginal staining, colour and translucency, anatomic form, fracture and retention, marginal adaptation, wear, contact point and proximal contour (when applicable), caries recurrence and dental integrity. Restorations were classified according to the need for intervention: (0) no intervention, (1) repair, and (2) replacement. No intervention was assigned for restorations judged clinically acceptable, with characteristics of grades 1, 2 or 3 of FDI criteria. Restorations compatible with grades 4 and 5 were considered as clinically unacceptable failures, with indication of repair or replacement, respectively.

4.2.5 | **Intraoral photographic method**

After the clinical examination, intraoral photographs were taken under standardized conditions, by one previously trained dentist for the use of photographic equipment. Each individual was positioned on a dental chair, with the Frankfort maxillary plane 45- to the floor and a disinfected cheek retractor was inserted into the patients' mouth. For each restoration, two photographs were taken with the camera located 3 cm from the tooth surface. The camera was positioned perpendicular to the buccal and lingual surface for anterior teeth, and in a 45-angle from the buccal and lingual direction for posterior teeth. The digital intraoral camera CS 1200 (Carestream Health Inc, Rochester, New York, USA) was used for all cases. The camera includes ranging from 3-25mm and has a 6-LED illumination, which adjusts automatically to environmental practice light conditions. In relation to quality and size of images, the camera delivers a 1024x768 fixed image resolution. All images were registered and stored in a database. No image correction related to color, brightness, and contrast was performed. Figure 1 shows examples of photographs used in the study for anterior and posterior restorations with and without failures.

4.2.3 | **Photographic evaluation**

Three trained dentists (KC, MBC, NO) who participated in previous clinical studies as an evaluator using FDI criteria and who did not participate in the data collection evaluated the photographs based on the FDI criteria [12]. The recorded images were projected at the same time for all examiners by one of the authors, using 50" HD television in a dark room. The examiners evaluated independently each restoration, without knowledge of the answers of the other evaluators. Moreover, evaluators indicated the need for intervention for each restoration based on simplified FDI criteria: (0) no intervention (grades 1, 2, 3); (1) repair (grade 4); and (2) replacement (grade 5). Following the separate evaluation, a final photographic diagnosis was set based on the classification agreement between at least two of the three evaluators (Consensus). One month after the clinical evaluation, the gold standard examiner (MSC) also evaluated the restorations from the photographs in the same way as the other examiners.

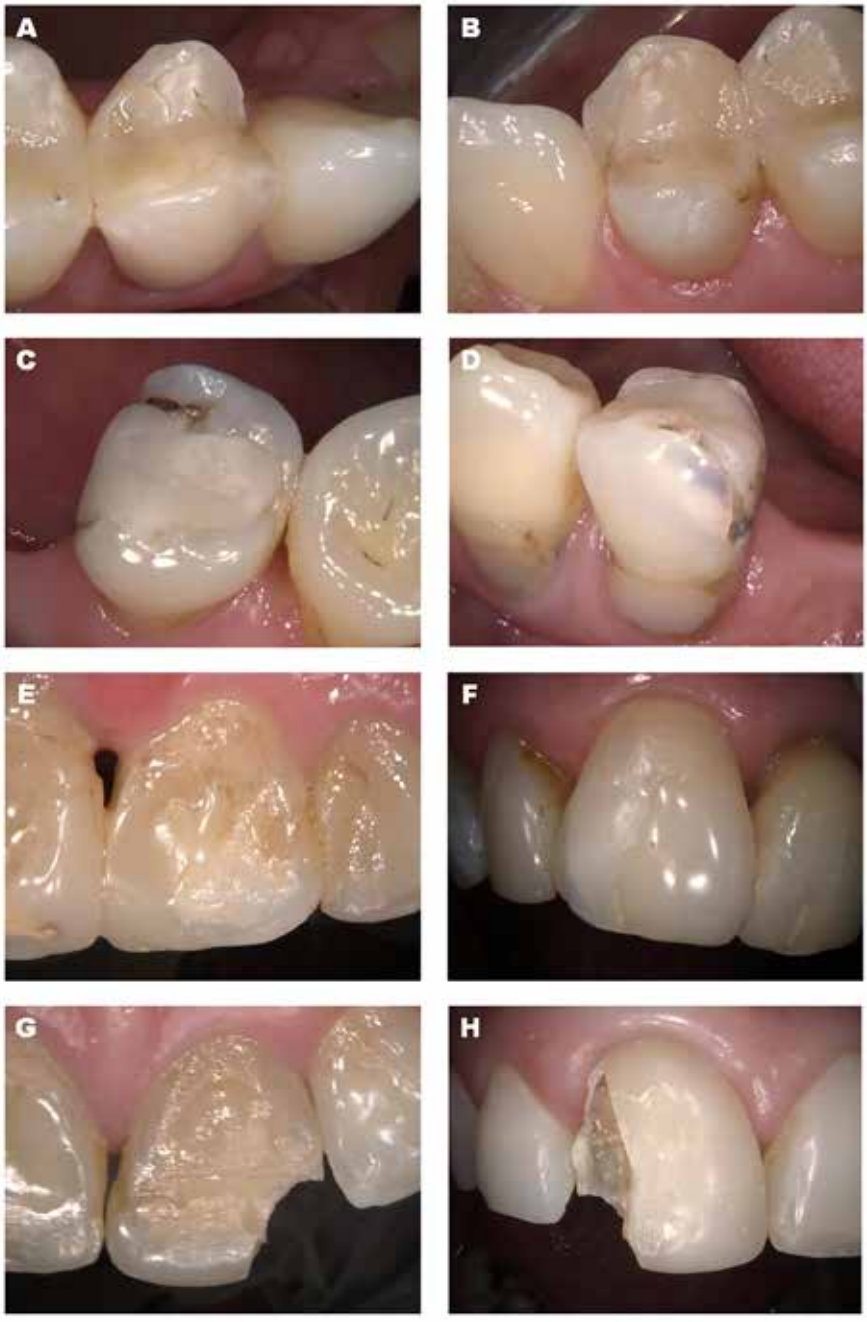

FIGURE 1 | Digital photographs of restorations. Each restoration is shown at two different angles (A/B, C/D, E/F and G/H). A/B: posterior restoration without failure; C/D: posterior restoration with failure; E/F: anterior restoration without failure; G/H: anterior restoration with failure.

4.2.4 | **Statistical analysis**

Data were double typed and statistical analysis was conducted with STATA/SE 12.0 (Stata Corp, College Station, TX, USA). The prevalence of failed restorations according to the gold standard and to the photographic method with respective 95% confidence intervals (95% CI) was calculated. Level of agreement between the clinical and photographic evaluation of failed restorations was assessed. The Cohen's kappa statistic was used to measure the reproducibility of the intraoral photographic method and the reproducibility of each of the dentists and the consensus evaluation compared to the reference standard method (clinical examination). For the calculation of agreement of total of failures, a dichotomized score was used: 0 - no failure, 1 - failure (restorations indicated for repair or replacement). Weighted kappa was used to calculate the agreement regarding the indication of repair or replacement due to the 3 possible categories (0 - no intervention, 1 - repair, 2 - replacement). Kappa interpretation was the following: ≤0.20 (poor), 0.21-0.40 (fair), 0.41-0.60 (moderate), 0.61-0.80 (good), and 0.81-1.00 (very good) [31]. Sensitivity (SE), specificity (SP), positive predictive value (PPV), negative predictive value (NPV), positive likelihood ratio (PLR), negative likelihood ratio (NLR), as well as accuracy of the photographic method (with respective 95% confidence intervals) in comparison with clinical examination to detect failed restoration were calculated.

4.3 | **Results**

A total of 55 patients with 198 composite resin restorations were included in the sample (128 posterior and 70 anterior restorations). 46 restorations had one surface, 72 two surfaces and 80 had three or more surfaces.

The prevalence of failures diagnosed by the evaluators in anterior and posterior restorations requiring repair or replacement is presented in Table 1. In general, a higher number of failed restorations was identified by intraoral digital photography (consensus: 17.7%) compared to the clinical evaluation (14.1%). Remarkably, there was a substantial increase in the number of cases indicated for repair by the gold-standard evaluator from photographs (17.7% including 14.1% anterior and 24.3% posterior) compared to his own clinical assessment (11.1% including 12.9% anterior and 10.2% posterior). Also, differences in assessments between evaluators can be observed with for example 24.3% and 5.7% anterior restorations indicated for repair by respectively the gold standard evaluator and evaluator 2.

TABLE 1 | Prevalence of failure with indication of intervention attributed by the evaluators in clinical and photographic assessments.

Evaluation	Prevalence of failures					
	Repair		Replacement		Total of failures	
	n (%)	95%CI	n (%)	95%CI	n (%)	95%CI
Posterior + Anterior (n=198)						
Clinical assessment						
Gold standard evaluator	22 (11.1)	7.1-16.3	6 (3.0)	1.1-6.3	28 (14.1)	9.6-19.8
Digital photographic assessment						
Gold Standard evaluator	35 (17.7)	12.6-23.7	11 (5.6)	2.8-9.7	46 (23.3)	17.5-29.7
Evaluator 1	29 (14.7)	10.0-20.2	14 (7.1)	3.9-11.6	43 (21.7)	16.2-28.1
Evaluator 2	12 (6.1)	3.2-10.3	14 (7.1)	3.9-11.6	26 (13.1)	8.8-18.6
Evaluator 3	26 (13.1)	8.8-18.6	8 (4.0)	1.8-7.8	34 (17.2)	12.2-23.2
Consensus[1]	24 (12.1)	7.9-17.5	11 (5.6)	2.8-9.7	35 (17.7)	12.6-23.7
Posterior (n=128)						
Clinical assessment						
Gold standard evaluator	13 (10.2)	5.5-16.7	3 (2.3)	0.5-6.7	16 (12.5)	7.2-19.5
Digital photographic assessment						
Gold Standard evaluator	18 (14.1)	8.6-21.3	8 (6.3)	2.7-11.9	26 (20.4)	13.7-28.3
Evaluator 1	18 (14.1)	8.6-21.3	9 (7.0)	3.3-12.9	27 (21.1)	14.4-29.2
Evaluator 2	8 (6.3)	2.7-11.9	10 (7.8)	3.8-13.9	18 (14.1)	8.6-21.3
Evaluator 3	19 (14.8)	9.2-22.2	5 (3.9)	1.3-8.9	24 (18.7)	12.4-26.6
Consensus[1]	18 (14.1)	8.6-21.3	6 (4.7)	1.7-9.9	24 (18.7)	12.4-26.6
Anterior (n=70)						
Clinical assessment						
Gold standard evaluator	9 (12.9)	6.1-23.0	3 (2.3)	0.3-9.9	12 (17.1)	9.2-28.0
Digital photographic assessment						
Gold Standard evaluator	17 (24.3)	14.8-36.0	3 (4.3)	0.9-12.0	20 (28.6)	18.4-40.6
Evaluator 1	11 (15.7)	8.1-26.4	5 (7.1)	2.4-15.9	16 (22.9)	13.7-34.4
Evaluator 2	4 (5.7)	1.6-14.0	4 (5.7)	1.6-14.0	8 (11.4)	5.1-21.3
Evaluator 3	7 (10.0)	4.1-19.5	3 (4.3)	0.9-12.0	10 (14.3)	7.1-24.7
Consensus[1]	6 (8.6)	8.6-21.3	5 (7.1)	2.4-15.9	11 (15.7)	8.1-26.4

[1]*Consensus was based on the agreement of at least two of the three evaluators (1,2 and 3).*

Table 2 shows the agreement between intraoral photography assessment in comparison to the clinical evaluation (reference standard method) for anterior and posterior restorations. Moderate agreement based on kappa values was shown between the digital photographic and clinical evaluation for the gold standard evaluator (0.51) and consensus of evaluators (0.53) related to the total of failures for posterior and anterior teeth. Regarding repair and replacement analysis, the agreement was moderate for posterior teeth. In contrast,

for anterior teeth it was fair for the gold standard and consensus (0.29), ranging from slight (0.12) to fair (0.34) between evaluators. Considering the total number of failures, gold standard and consensus showed substantial and moderate agreement for posterior restorations (kappa values = 0.61; 0.59), with fair and moderate agreement for anterior restorations (kappa values = 0.36; 0.43), respectively.

TABLE 2 | Level of agreement in the evaluation of digital photography of anterior and posterior restorations compared to clinical assessment (Reference Standard = RS).

Evaluation	Repair and replacement		Total of failures	
	Kappa value	Agreement with RS	Kappa value	Agreement with RS
Posterior + Anterior (n=198)				
Gold Standard evaluator	0.44	89.1	0.51	84.9
Evaluator 1	0.37	87.6	0.44	83.3
Evaluator 2	0.30	88.4	0.44	86.9
Evaluator 3	0.48	91.4	0.54	87.9
Consensus[1]	0.45	90.4	0.53	87.4
Posterior (n=128)				
Gold Standard evaluator	0.55	91.8	0.61	89.1
Evaluator 1	0.44	89.5	0.48	85.2
Evaluator 2	0.41	90.2	0.60	90.6
Evaluator 3	0.57	93.0	0.59	89.1
Consensus[1]	0.56	92.6	0.59	89.1
Anterior (n=70)				
Gold Standard evaluator	0.29	84.3	0.36	77.1
Evaluator 1	0.27	84.3	0.38	80.0
Evaluator 2	0.12	85.0	0.19	80.0
Evaluator 3	0.34	88.6	0.46	85.7
Consensus[1]	0.29	86.4	0.43	84.3

[1]*Consensus was based on the agreement of at least two of the three evaluators (1,2 and 3).*

The validity of the intraoral digital photography compared to clinical examination based in the gold standard assessments is shown in Table 3. Sensitivity and specificity values for all restorations evaluated were 78.6% and 85.9%, with an accuracy of 84.8%. The positive predictive value was 47.8%, and the negative predictive value was high (96.1%). A small likelihood ratio of a negative test (0.25) and moderate likelihood ratio of a positive test (5.6) were achieved. Higher sensitivity (87.5%) and specificity (89.3%) were found considering only restored posterior teeth in comparison to anterior restorations (66.7% and 79.3%), with an increase in the negative and positive predictive value, likelihood ratio of a positive test and decrease in the likelihood ratio of a negative test.

TABLE 3 | Validity of the gold standard obtained by digital photographic assessment compared to clinical examination.

	Failure of Restoration	Clinical examination (reference standard)		Total
		Present	Absent	
Posterior + Anterior (n=198)				
Intraoral digital photographic	Present	22	24	46
	Absent	6	146	152
	Total	28	170	198
Sensitivity: 78.6% (95% CI 59.0–91.7); Specificity 85.9% (79.7–90.7); Positive predictive value (PPV): 47.8%; Negative predictive value (NPV): 96.1%; Likelihood ratio of a positive test (PLR) 5.6 (3.7–8.5); Likelihood ratio of a negative test (NLR) 0.25 (0.12–0.51).				
Posterior (n = 128)				
Intraoral digital photographic	Present	14	12	26
	Absent	2	100	112
	Total	16	112	128
Sensitivity: 87.5% (95% CI 61.7–98.4); Specificity 89.3% (82.0–94.3); Positive predictive value (PPV): 53.8%; Negative predictive value (NPV): 98.0%; Likelihood ratio of a positive test (PLR) 8.2 (4.6–14.4); Likelihood ratio of a negative test (NLR) 0.14 (0.04–0.51).				
Anterior (n=70)				
Intraoral digital photographic	Present	8	12	20
	Absent	4	46	50
	Total	12	58	70
Sensitivity: 66.7% (95% CI 39.9–90.1); Specificity 79.3% (66.6–88.8); Positive predictive value (PPV): 40.0%; Negative predictive value (NPV): 92.0%; Likelihood ratio of a positive test (PLR) 3.2 (1.7–6.1); Likelihood ratio of a negative test (NLR) 0.42 (0.19–0.95).				

4.4 | Discussion

To our knowledge, this is the first study that examined the validity of assessment of digital photography using an intraoral camera in the evaluation of anterior and posterior dental restorations, in comparison to clinical examination. The findings of this study showed good accuracy (84.8%) and moderate agreement for the intraoral photography method in the diagnosis of restoration failures. Considering these results, added to sensitivity, specificity, predictive values and positive and negative likelihood ratio, we can conclude that the assessment of digital intraoral photography is valid to evaluate quality of restorations, mainly in posterior teeth.

Different methods are available to evaluate dental restorations, with different levels of precision [11, 23, 32]. Intraoral digital photography has been increasingly used in the clinical

routine as an auxiliary method for diagnosis, treatment planning and for dental records [27]. This method allows initial registration of a treatment performed by the dentist, archiving of images, and subsequent follow-ups, which is important in long-term follow-up surveys of restorations, especially in randomized controlled trials and prospective studies based on clinical practice [26-28]. The storage of treatment images by dentists may result in significant information, and it is a promising field of research [26]. It allows the blindness of potential examiners and cases analysis by a single examiner in multicentre studies, resulting in the reduction of bias. Furthermore, a main advantage of the method is the opportunity to evaluate dental restorations independently without the necessity of an on-site evaluation where evaluators should schedule appointments with patients.

The use of digital photography to evaluate the quality of restorations provided more information about the clinical condition of restorations compared to the clinical examination in a previous study [33]. Also, our results showed an increased number of defects detected by images, since a higher prevalence of failures was diagnosed by photographs compared to clinical findings, resulting in more indication for repair and replacement of restorations. In addition, previous studies have identified a high prevalence of fluorosis by photographic examination compared to clinical examination [34,35]. Magnified images as projected on a large screen likely show defects that are not noticed clinically [33,36-38] increasing the number of restorations planned for replacements [39]. The amount of time available to evaluate the images of the cases can also impact on the observation of more defects, since during the clinical examination some items may be overlooked or missed [40]. For assessing the quality of restorations and comparing different materials and other variables in dentistry like operators and patient factors, this might be advantageous, as small differences might be noticed earlier. However, relying on these assessments for clinical decision making would possibly leads to overtreatment as restorations still functioning well according to patients demands could be classified as failed and in need for operative intervention [33]. Therefore, the authors would recommend the method of using intra-oral photographs for research purposes while care should be taken when using them for supporting clinical decision making.

Other aspects to be considered in the assessment are the restricted visualization of proximal and cervical areas [36], and the lack of complementary information related to the restoration probing in comparison to the clinical examination [33]. Factors such as the examiner's position in the clinical exam and the recording angle of the photograph may also affect the diagnostic decision [16]. Especially for evaluating restorations placed in regular care, routinely made bitewing radiographs might be useful to overcome these disadvantages.

Considering the diagnosis of total failures, moderate agreement was found between photographic and clinical assessment, which was also reported by Moncada et al. [33]. In our study, we included anterior and posterior teeth, which also played a role in the diagnostic agreement. An increased level of agreement was shown in the analysis of

only posterior teeth while in the assessment of anterior restorations differences between evaluators were considerable. The evaluation of the quality of anterior restorations is likely more difficult compared to posterior restorations due to the aesthetic implications, which is a property with lower reliability [25]. The reasons for failure for anterior restorations are directly or indirectly related to the aesthetic appearance, which is subjective and vary between individuals depending on the educational level, age and environment in which they are inserted [41]. Thus, the assessment of factors related to the aesthetic by several dental general practitioners in PBRN does not seem to be able to provide consistent results due to the lack of agreement between examiners. Perhaps, the aesthetic aspect should be reported by the patient in clinical research, since the patient's demand is the key factor for the decision to intervene.

Restorations were assessed based on the International Dental Federation criteria, composed by 3 categories (aesthetic, functional and biological) and 5 scores that classify the restorations as clinically acceptable or not [12]. The criteria have been widely used in studies [42-44] due to the need to standardize assessments. However, despite being a detailed criterion, it showed slight to fair reliability in the evaluation of photographic images of posterior restorations, which can be justified in part by the choice between adjacent scores that can be difficult and susceptible to different interpretations [25]. In PBRN studies the main outcome of interest is normally the failure of the restoration, therefore the detailed collection of each criteria as reported by FDI is not so crucial in this type of study. For this reason, we simplified the criterion based on the decision to intervene (repair or replacement) or not, providing more consistent information. The evaluations were established from a minimally invasive perspective, considering replacement of restorations as a last alternative [8]. The treatment of choice in the management of restorations was based in the conservative approach of monitoring and repair [11].

Considering the validity of the assessment by the digital photographic method high specificity and sensitivity were shown, which was seen in previous studies in the diagnosis of dental conditions [18,20,45]. And although differences were observed in the sensitivity and specificity values obtained for posterior (87.5% and 89.3%, respectively) and anterior restorations (66.7% and 79.3%), in both cases the sum of sensitivity and specificity values exceeded 120%, which classifies the method as accurate according to a previous study [46]. Regarding the likelihood ratio, which measures the probability of a specific diagnosis occurring in the presence or absence of a condition of interest, our results showed moderate effect for the positive likelihood ratio in the general assessment of the cases, and low values for negative likelihood ratio, which is a good indicator for the effectiveness of the test [47]. High negative predictive value and low positive predictive value were found. This could be explained due to the low prevalence of failures in the study population, as the predictive values are dependent on the prevalence of the condition [48].

Thus, the hypothesis of the present study was partially accepted as although the photographic assessment has shown adequate results for a diagnostic method; a higher number of defects were identified using images in comparison with the clinical examination. Therefore, the photographic detection method should be used with care when used as a basis for restorative intervention in order to avoid over-treatment. The digital images have good potential for use in PBRN, since it allows quick and permanent recording of restorations, and comparison in time is possible between subsequent recordings [18,26,49]. Future research should focus on the development of a guideline for standardization of the method and use of simplified clinical criteria for the assessment of restorations in clinical research.

4.5 | Conclusions

Under the limits of this study, the assessment of digital photography performed by intraoral camera is an indirect diagnostic method valid for the evaluation of dental restorations and is especially useful for posterior teeth. The method results in more defects provided by the images, compared to the clinical assessment and care should be taken for clinical decision making based on intraoral images.

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5

CHAPTER 5

Decision-making of general practitioners on interventions at restorations based on bitewing radiographs

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Abstract

Objective The aim of this study was to compare decision-making based on bitewing analysis of restored proximal surfaces by General Dental Practitioners (GDPs) with diagnosis and clinical decisions made by experts in cariology and restorative dentistry.

Methods This practice-based study used a database of 7 general dental practices. Posterior bitewing radiographs were selected from the electronic patient files of patients and 770 cases of proximal restored surfaces were elected. Fifty per cent of the cases which lead to the restorative decision, and the other half were cases decided for monitoring by the GDPs. Three experts performed radiographic assessment. The outcome variables were agreement of diagnosis and decision of treatment. Cohen's kappa statistic was used.

Results For the experts, moderate to substantial intraexaminer agreement was observed for the diagnostic criteria, and kappa values of 0.77, 0.79 and 0.88 were obtained for each expert regarding the treatment assignment. Agreement between GDPs and the majority of experts for secondary caries varied between 67% and 83%. 173 out of 385 cases that were treated by GDPs were decided for monitoring by the experts while 8 cases that were decided for monitoring by the GDPs were decided for treatment. The agreement between experts and GDPs was moderate for secondary caries detection, and fair for treatment decision.

Conclusion The GDPs tend to have a less conservative approach regarding the decision to intervene or not concerning the reassessment of restorations, showing moderate agreement with the experts for secondary caries detection and fair agreement to the treatment decision.

Clinical significance
This study highlights that GDPs tend to have a less conservative approach related to the decision to intervene or not in posterior restorations, compared to experts in cariology and restorative dentistry. Efforts should be made to reduce these differences based on minimally invasive dentistry.

5.1 | Introduction

The detection of proximal secondary caries is a challenge for the general dental practitioner (GDP) in daily clinical routine [1]. Bitewing radiographs are traditionally used to examine interproximal restored surfaces [2], since the presence of adjacent teeth and gingival tissue in cervical areas do not allow an appropriate visual inspection of marginal defects, such as overhang, ditches and gaps [3]. However, radiographic detection of marginal gaps may lead to false-positive and false-negative treatment decisions, including underestimation of caries lesion size [4]. Moreover, misinterpretations may occur due to difficulties in distinction between restorative materials and tooth tissue, depending on radiopacity of materials [5].

Substantial variability in diagnosis and subsequent decision-making of restorations between dentists has been reported [6–8], which may be due to the lack of standardized diagnostic criteria and treatment guidelines for monitoring, restoring or replacing a defective restoration [9]. As a result, the decision on how and when to intervene continues to be subject of discussion [9–11] and it is unclear if dental practitioners and professionals from the academic field share a common understanding of restorative treatment decision. Several studies investigated the treatment decision related to radiographic diagnosis of primary caries in proximal surfaces in posterior teeth [12,13], while a limited number addresses the diagnosis and decision-making in restored surfaces [4,14]. There is need to clarify reasons for the decision to intervene restoratively on a defective restoration [15], and improve the treatment decision based on radiographic assessments [16], ensuring the patient receives the best dental health care avoiding overtreatment [1,17].

Secondary caries is reported as the most common reason to replace or repair a defective dental restoration in general practices [18,19] while in controlled studies, performed at the Academia, secondary caries is seldomly observed [20,21]. This brings up the issue whether GDPs correctly diagnose secondary caries or instead, misjudge discoloured margins and imperfect marginal fit as secondary caries [22]. Therefore, the investigation of clinical decision-making on defective restorations in a network of General Dental Practitioners (GDPs) is interesting, as it allows access to the clinical information of actual treatments performed by GDPs [23]. The aim of this study was to compare the outcome of clinical decision-making by GDPs based on the analysis of bitewings with decisions made by experts in cariology and restorative dentistry analyzing the same bitewings. The hypothesis of the study was that experts and GDPs would have a reasonable agreement in the detection of secondary caries and treatment decision, while a more conservative approach would be adopted by the experts in decision-making compared to GDPs.

5.2 | Materials and methods

5.2.1 | Study design

This was a practice-based study conducted from a database with clinical records from 7 general dental practices. Posterior bitewing radiographs of proximal surfaces with different status concerning secondary caries lesions and defective restorations were randomly selected from files. Three experts in the areas of cariology and restorative dentistry (FMM, MSC, NO) performed the radiographic assessment. The outcome variables were agreement of diagnosis and decision of treatment between experts and GDPs. Ethical approval was granted by the local Ethics Committee METC (CMO file nr. 2015-1565).

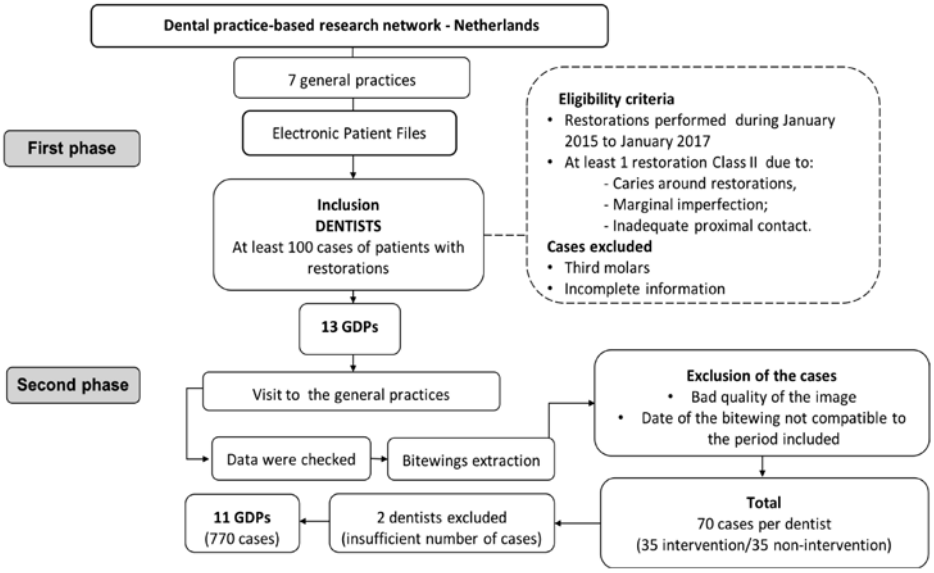

FIGURE 1 | Flow diagram of case selection.

5.2.2 | Sample characterization and eligibility criteria

Data were collected from a dental practice-based research network in the Netherlands (Figure 1). Clinical records from seven general practices were used, including 2 solo practices, 3 small (2-3 dentists) and 2 larger (more than 4 dentists) group practices. Five practices were located in urban areas and 2 in rural areas. Data from the Electronic Patient Files (EPF) of the patients were digitally extracted into a Microsoft® Excel file (Microsoft, Redmond, WA, USA) from the EPF software (Exquise®, Kwadijk, NL; Complan®, Heerhugowaard, NL). Cases registered in the period between January 2015 to January 2017 from patients attending a regular checkup were included. For eligibility in the study, those patients that received at least one restoration in a posterior tooth due to the detection

of 'caries around restorations', 'marginal imperfection' (lack of material or overhang) or inadequate proximal contact were selected. Only Class II restorations in 2 or more surfaces were included in the study sample while third molars were excluded. Patient files with incomplete information were excluded too. Furthermore, each included dentist should have at least 100 restorations meeting the inclusion criteria. In total, this resulted in 13 dentists to be included in this phase.

5.2.3 | Data collection and selection

Seven dental practices located in different cities in the Netherlands were visited. During the visits, data of the included patients were checked, and the bitewing radiographs were extracted from the EPF. Cases without appropriate radiographs either due to the date or quality of the image were excluded from the sample. Dates of dental visits and bitewings radiographs were used as a parameter to confirm the treatment decision made by dentists (intervention or non-intervention) at the time of the digital bitewing analysis. For instance, in those cases where the intervention was performed following the x-ray, the treatment decision attributed by the dentist was classified as 'intervention'. On the other hand, in those cases that the checkup including bitewings did not lead to a restorative intervention before another checkup had taken place, or in cases where no intervention was performed within the period of 6 months after bitewing radiographs were taken, the dentist's treatment decision was classified as non-intervention (at the time of the x-ray interpretation). Also, cases of restored teeth present in the x-rays without intervention during the period of the study were considered as cases of non-intervention.

In total, 70 cases were selected per dentist. Thirty-five cases were cases of intervention and the same amount of cases where non-intervention was performed were randomly selected from the bitewings. Two dentists were excluded in this phase of the study due to an insufficient number of cases related to poor quality of images, or absence of radiographs in patient files. Thus, 770 cases from 11 dentists were included for assessment by the experts. For calculation of intraexaminer agreement 10% of cases were re-evaluated after 2 weeks, totaling to 847 cases for evaluation.

5.2.4 | Calibration of experts

Three experts (FMM, MSC and NO) with expertise in cariology and restorative dentistry from distinct university centers were invited to analyze a series of bitewing radiographs. Prior to the assessments the 3 experts received a sequence of cases for analysis and discussion. Following, a pilot test was conducted. 10 cases were individually evaluated for each expert. The agreement in most of diagnostic criteria, described above, was substantial (kappa > 0.60) to excellent (kappa > 0.86) regarding aspects related to the diagnosis, and moderate for intervention assignment (kappa 0.56). The experts were blind to the decisions made by the GPDs and to the other experts'decisions.

5.2.5 | Assessment of bitewings

Digital bitewing radiographs were inserted in a Microsoft® PowerPoint file (Microsoft, Redmond, WA, USA), coded and projected in a black background. Tooth number and surface were identified in each bitewing radiograph. The cases were divided in 3 parts available with one week of interval between each part for optimizing the assessments. Information related to the patient was not provided. The assessments were performed individually by the three experts. The presence of secondary caries, lack of material, overhang, inadequate contact point, radiolucent bond or cement layer, lack of adaptation and residual caries were assessed as likely present (1) or not likely present (0). In those cases that one or more of 3 aspects: overhang, lack of material and lack of adaptation, were scored as present, the cases were scored as lack of adaptation in the analysis.

Finally, the need for intervention was scored as: (0) no intervention, (1) more information is necessary for treatment decision, and (2) intervention.

5.2.6 | Statistical analysis

Statistical analysis was performed using the software Stata 11.0 (StataCorp LP, College Station, TX, USA). Final diagnosis and treatment decision for each case was based on the opinion of the experts majority. In those cases, the treatment decision ended in a tie, the case was defined as 'treatment decision not possible'. Cohen's kappa statistic was used to measure intra and interexaminer reliability of experts and interexaminer agreement between GDPs and experts. Weighted kappa was calculated only for the variable 'need for intervention' (treatment), as for this assessment 3 categories of responses were available (0 - no intervention/ 1 - more information is necessary for treatment decision/ 2 - intervention). For the comparison between GDPs and the scores obtained from the majority of experts regarding the 'need for intervention' kappa analysis was performed in two ways as the category 'more information is necessary for treatment decision' was not an option for GDPs. First assuming 'non-intervention' for the cases assigned by the majority of experts as 'more information in necessary' (kappa 1), and in a second analysis assuming 'intervention' for the same cases (kappa 2). Only those cases where it was possible to establish a majority of opinion between experts were considered in the analysis. The relative strength of agreement associated with kappa values was interpreted as follows: <0.00 (poor), 0.00-0.20 (slight) 0.21–0.40 (fair), 0.41–0.60 (moderate), 0.61–0.80 (substantial), and 0.81–1.00 (excellent) [24].

5.3 | Results

The conditions as detected by the experts for the 770 cases are shown in Table 1. This table also shows the treatment decisions of the experts related to the diagnostic conditions

as reported separately and associated. 359 cases were assigned with only one condition detected of which 119 were assessed as secondary caries. Of those 8 were assessed for no intervention while other cases were either requiring more information, assessed as tied judgement or assessed for intervention. 82 additional cases received the diagnosis secondary caries with one additional other condition. Of those, 7 were assessed for no intervention. Two or more conditions were detected in 157 cases without the diagnosis secondary caries. Of those cases, 140 were advised for monitoring (no intervention).

TABLE 1 | Distribution of treatment decisions based on the opinion of the majority of experts related to diagnosis reported separately and associated (n = 770).

Experts (majority)	**No intervention**	**More information**	**Intervention**	**Opinion of the majority not established***	**Total**
Examined conditions not found (n = 109)					
	109 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	109 (100.0)
Only 1 condition detected per case (n = 359)					
secondary caries	8 (6.7)	11 (9.2)	57 (47.9)	43 (36.1)	119 (100.0)
residual caries	17 (94.4)	0 (0.0)	0 (0.0)	1 (5.6)	18 (100.0)
inadequate contact point	19 (95.0)	0 (0.0)	1 (5.0)	0 (0.0)	20 (100.0)
lack of adaptation	89 (97.8)	2 (2.2)	0 (0.0)	0 (0.0)	91 (100.0)
bond layer	109 (98.2)	2 (1.8)	0 (0.0)	0 (0.0)	111 (100.0)
Secondary caries linked with another condition (n = 82)					
secondary caries + residual caries	1 (16.7)	2 (33.3)	0 (0.0)	3 (50.0)	6 (100.0)
secondary caries + inadequate contact point	2 (15.4)	2 (15.4)	6 (46.2)	3 (23.1)	13 (100.0)
secondary caries + lack of adaptation	2 (3.7)	9 (16.7)	23 (42.6)	20 (37.0)	54 (100.0)
secondary caries + bond layer	2 (22.2)	4 (44.4)	1 (11.1)	2 (22.2)	9 (100.0)
Secondary caries linked with 2 or more conditions (n = 63)					
	6 (9.5)	22 (34.9)	24 (38.1)	11 (17.5)	63 (100.0)
Cases with 2 or more conditions, without secondary caries (n = 157)					
	140 (89.2)	10 (6.4)	1 (0.6)	6 (3.8)	157 (100.0)

**Each expert made a different decision, it was not possible to establish the opinion of the majority of experts.*

TABLE 2 | Intraexaminer and interexaminer reliability considering the evaluations made by the experts.

	Intraexaminer						Interexaminer					
	Expert A		Expert B		Expert C		Experts A - B		Experts A - C		Experts B - C	
Criteria	Kappa	Agreement (%)	Kappa	Agreement (%)	Kappa	Agreement (%)	Kappa	Agreement (%)	Kappa	Agreement (%)	Kappa	Agreement (%)
Secondary caries	0.84	92.21	0.84	96.10	0.73	87.01	0.24	63.38	0.50	74.94	0.28	67.14
Lack of material	0.54	88.31	0.50	80.52	0.51	84.42	0.25	73.12	0.32	78.10	0.42	78.31
Overhang	0.74	92.21	0.62	87.01	0.76	90.91	0.60	87.40	0.55	85.32	0.63	86.75
Inadequate contact point	0.69	94.81	0.69	89.61	0.64	88.31	0.49	86.49	0.48	85.32	0.64	87.92
Bond layer or cement layer	0.54	80.52	0.36	72.73	0.42	71.43	0.24	67.70	0.41	71.95	0.28	65.45
Lack of adaptation	0.51	85.71	0.39	87.01	0.39	87.01	0.08	75.84	0.15	76.88	0.35	83.90
Residual caries	0.48	79.22	0.50	79.22	0.58	90.91	0.11	63.77	0.24	79.74	0.07	65.58
Treatment	0.88	83.12	0.79	92.21	0.77	76.62	0.32	70.78	0.40	74.35	0.43	80.97

In general, a moderate to substantial intraexaminer agreement was observed (Table 2) for the different diagnostic criteria, and substantial (kappa = 0.77; 0.79) to excellent agreement for the treatment assignment (kappa = 0.88). Interexaminers kappa values showed better results for the detection of overhang (0.55 to 0.60) and inadequate contact point (0.48 to 0.64), followed by the indication of treatment (0.32 to 0.43). Especially the detection of 'lack of adaptation' and 'residual caries' showed the lowest kappa values, ranging from 0.08 to 0.35, and from 0.07 to 0.24, respectively.

The comparison among experts and GDPs based on the clinical decisions of no intervention/intervention as decided by the GDPs can be found in Figure 2. Experts (majority) indicated intervention due to caries in 26.8% (103/385) of cases whereas GDPs placed a restoration in 90.6% (349/385) of cases. In those cases, with the detection of a condition other than caries, in 0.52% (2/385) of cases intervention was advised by the experts compared with 9.35% (36/385) actually restored by the GDPs. It was not possible to establish a majority opinion for 17.9% (69/385) of cases, and more information was needed for taking a decision in 9.9% (38/385) of cases. Concerning the 385 cases where no intervention was made by the GDPs, the majority of experts designated no intervention for 86% (331/385) of cases and intervention due to caries for 2.1% (8/385).

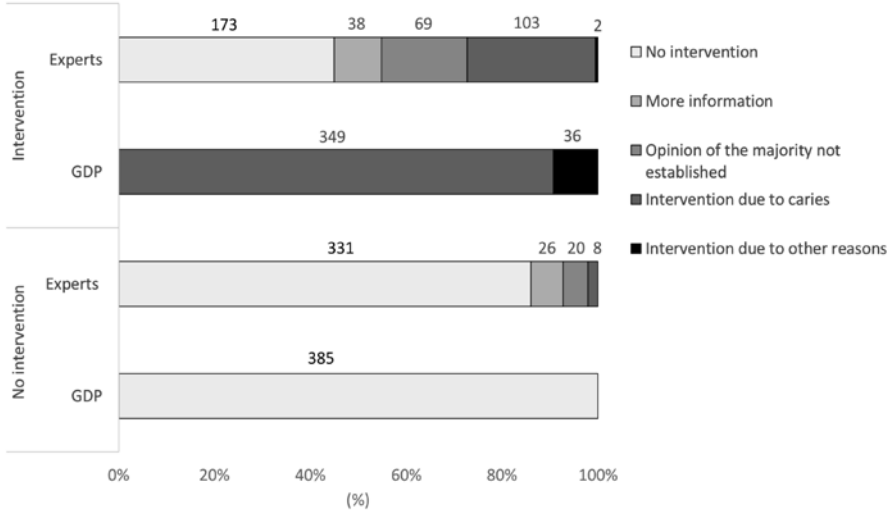

FIGURE 2 | Comparison of treatment decisions by GDPs and expert's judgements.
Note: The number of cases corresponding to each percentage are shown in bars.

Considering the cases in which at least 1 or more experts decided to intervene, not based on the majority (Figure 3), intervention due to caries was indicated in 54.8% (211/385) of cases compared to the indication of GDPs (90.6%). Of the total cases without intervention performed by the GDPs, 11.68% (45/385) were perceived by 1 or more experts as needing intervention due to caries.

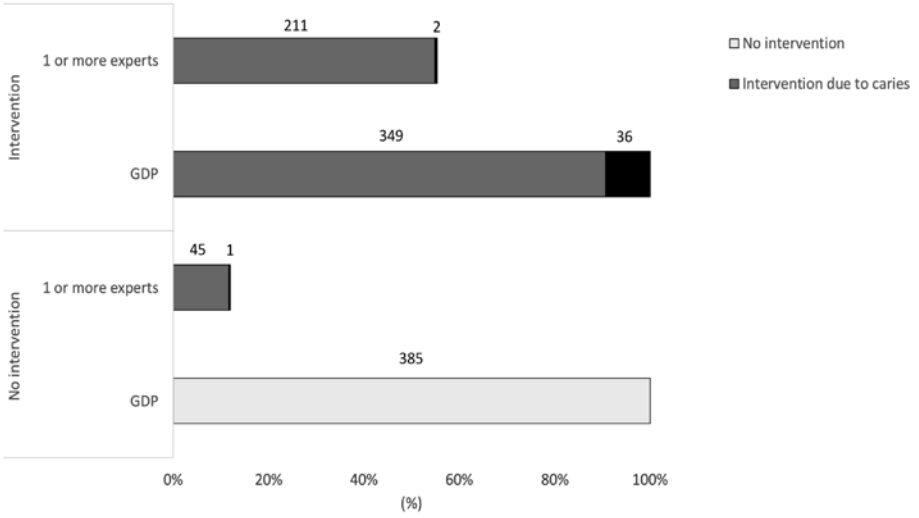

FIGURE 3 | Comparison of treatment decisions by GDPs and experts based in the cases in which 1 or more experts decided to intervene (not based in the opinion of the majority).

Note: The number of cases corresponding to each percentage are shown in bars.

Table 3 shows the comparison of agreement between each GDP and experts, and for the total of cases. The agreement at individual GDP level for the diagnosis of secondary caries varied greatly from 0.31 to 0.65 indicating an agreement level of 67-83%. For the decision to intervene, kappa values for the agreement between the majority of experts and individual practitioners varied from 0.16 to 0.65, representing 60-83% of percentage of concordance. There was an increase in most of the kappa values in the analysis considering the cases designated as 'more information is necessary for treatment decision' by the experts (majority) as 'intervention' (kappa2), compared to the analysis where no intervention was considered for the same cases (kappa1).

TABLE 3 | Comparison of agreement between General Dental Practitioners (GDP) with the opinion of the majority of experts regarding secondary caries and indication of intervention.

	Secondary caries				Intervention						
	Prevalence				Prevalence		Need of more information for decision				
	GDP n (%)	Experts (majority) n (%)	Kappa	Agreement (%)	GDP n (%)	Experts n (%)	n (%)	Kappa1*	Agreement1* (%)	Kappa2*	Agreement2* (%)
Individual (n = 70)											
GDP 1	34 (48.1)	34 (48.6)	0.43	71.43	35 (50.0)	17 (24.3)	8 (11.4)	0.37	68.33	0.37	68.33
GDP 2	25 (35.7)	25 (35.7)	0.44	74.29	35 (50.0)	7 (10)	9 (12.9)	0.26	65.08	0.31	66.67
GDP 3	33 (47.1)	24 (34.3)	0.45	72.86	35 (50.0)	11 (15.7)	4 (5.7)	0.38	69.49	0.52	76.27
GDP 4	30 (42.9)	23 (32.9)	0.55	78.57	35 (50.0)	8 (11.4)	11 (15.7)	0.25	66.13	0.39	70.97
GDP 5	33 (47.1)	31 (44.3)	0.60	80.00	35 (50.0)	20 (28.6)	8 (11.4)	0.65	82.81	0.65	82.81
GDP 6	32 (45.7)	27 (38.6)	0.45	72.86	35 (50.0)	17 (24.3)	2 (2.9)	0.44	72.58	0.44	72.58
GDP 7	34 (48.6)	18 (25.7)	0.36	68.57	35 (50.0)	7 (10.0)	5 (7.1)	0.26	65.63	0.24	64.06
GDP 8	28 (40)	19 (27.1)	0.28	67.14	35 (50.0)	8 (11.4)	5 (7.1)	0.23	63.93	0.28	65.57
GDP 9	35 (50)	19 (27.1)	0.49	74.29	35 (50.0)	4 (5.7)	3 (4.3)	0.16	62.90	0.21	64.52
GDP 10	33 (47.1)	27 (38.6)	0.65	82.86	35 (50.0)	8 (11.4)	6 (8.6)	0.28	67.80	0.45	74.58
GDP 11	32 (45.7)	17 (24.3)	0.31	67.14	35 (50.0)	6 (8.6)	3 (4.3)	0.20	61.54	0.17	60.00
Total (n=770)	349 (45.3)	264 (34.3)	0.46	73.64	385 (50.0)	113 (14.7)	64 (8.3)	0.32	67.84	0.37	69.60

Note: kappa1 - Cohen's kappa statistical analysis was performed assuming 'non-intervention' for the cases assigned by the majority of experts as 'more information is necessary for treatment decision'. kappa2* - Cohen's kappa statistical analysis was performed assuming 'intervention' for the cases assigned by the majority of experts as 'more information is necessary for treatment decision'.*

Figure 4 shows examples of cases in which there was agreement between experts and GDPs regarding the decision of intervention, and cases in which there was disagreement.

FIGURE 4 | Digital bitewing radiographs assessed in the study illustrating cases of agreement and disagreement between experts and GDPs. The arrow indicates the element/surface that was analyzed. A: Case in which GDP and experts decided to intervene due to secondary caries. B/C/D: Cases in which GDPs and experts decided not to intervene. E/F/G/H: Cases in which GDPs decided to intervene due to secondary caries and experts decided not to intervene.

5.4 | **Discussion**

This study compared diagnosis and restorative treatment decisions though bitewings assessed by GDPs and by experts with expertise in cariology and restorative dentistry evaluating the same radiographic images. The selection of bitewing radiographs was based on restorations that were diagnosed by the GDP for repair or replacement due to the diagnosis of secondary caries. So, we hypothesized that the experts would reach that conclusion in most of these cases. The present study showed that secondary caries and lack of adaptation are often reported by the experts. However, lack of adaptation as scored by the experts, seldom lead to the decision to intervene while secondary caries was the predominant defect leading to intervention advised by the experts. Furthermore, fewer restorative interventions were indicated by the experts in comparison to the practitioners, indicating a more conservative approach. In addition, although a reasonable agreement was found among GDPs and experts regarding the detection of secondary caries, a fair agreement was observed considering the treatment decision-making. Therefore, the hypothesis of the study was partially accepted.

There are some critical remarks that have to be made to the applied method. For the GDPs, patients were examined clinically routinely during a check-up and the decision was made to make bitewing radiographs additionally to the clinical inspection. That results in two different types of examinations that are compared in the present study: one that is based on clinical examination and bitewings (GDPs) and the other one only based on bitewing radiographs (Experts). Therefore, GDPs had more information on patient's personal risk factors as well as visual and tactile observations including the surfaces that were investigated. Therefore, it is likely that GDPs decisions and expert decisions show differences and the more conservative approach as mentioned before from the experts may be not so obvious if experts were also given the opportunity to examine the patients in the same way as the GDPs.

Another aspect that needs to be addressed is that for the study cases were included that were decided for restorative intervention by the GDPs due to mainly the diagnosis secondary caries. This will result in an inclusion bias as likely many high risk patients were included and the population is not representative for the general population of patients attending those practices for check-up. In fact, only 109 of the 770 investigated cases were not diagnosed as imperfect by the experts. It is important to address that this amount of imperfections on the investigated surfaces is not indicative for the quality of the work performed by the dentists. Moreover, also minor imperfections like small overhangs, radiolucent bonding layers etc. were assessed as imperfect but by no means would be a reason to intervene, as neither the GDPs did nor the experts advised.

The selection of cases presented to the experts was either based on the actual decision made by the dentist to intervene (in 50% of the cases), or by the presence of restored

surfaces that were not restored by the dentists, but often showed some signs of imperfection (50% of cases, as selected by the researchers). Although the GDPs decided not to intervene those restorations could be subject to the expert advice to intervene, as was actually the case with 8 inspected surfaces (Figure 2).

While the selected patient population was likely not representative, also the dentist population might be not representative for GDPs in general. The GDPs joining the practice-based research network were all motivated dentists interested in evaluating their quality of work. Another limitation of this study is the number of cases obtained per each GDP which is based on the cases available in the dental practices. The choice for increasing this number would result in the exclusion of more GDPs from the sample. In addition, the use of intraoral photography associated with bitewings radiographs would be interesting to add information to the cases and may support the experts in diagnosis and treatment decision. Unfortunately, there was no photographic record of the cases. Future research should focus on the use of intraoral photography associated with radiographic exam to investigate the impact of the amount of information in the clinical decision allocation [25].

The use of bitewing radiographs allows visualization of defects not noticed clinically [26]. Lack of adaptation, as overhang and underfilled margins, was observed in a number of proximal restorations, as also reported in previous studies [4,27]. Besides, the presence of bond layer and residual caries were found in several cases, as shown by a translucent halo underneath the restoration. Those conditions can be erroneously interpreted as a restoration failure [28], mainly in situations without access to the clinical history of the patient.

Secondary caries is the most common reason for operative intervention in proximal restorations [29]. It was frequently found in the analyzed radiographs, especially in association with lack of adaptation. However, deficient adaptation does not necessarily imply the occurrence of secondary caries, which will occur only in patients with active caries and high risk [30]. Marginal defects are poor predictors of caries around restorations [31], and have limited clinical relevance, since it has already been reported that the presence of defects will not predict the longevity of the restoration [21], and in general is not an indication for operative treatment. This conception is reflected in our study, since in several cases where one or more defects were found no intervention was indicated by GDPs as well as experts.

The experts tended to show a more conservative approach in relation to the GDPs, based in the cases where intervention was performed due to secondary caries or other reasons. The comparison between the dentists and experts for the treatment decision was reported in two ways, first in comparison to the majority of experts opinion, and then considering when at least one of the experts decided to intervene in the cases. Although the second comparison showed a smaller difference in the indication of intervention

between dentists and experts, both reflected a more conservative approach adopted by the experts. As mentioned before, this may be related to the circumstance that experts were not able to do a clinical examination of the cases. The need for more information was pointed out by the experts in some cases. Additionally, in part of the cases it was not possible to obtain the opinion of the majority since each expert chose a different option regarding the treatment (no intervention/more information in necessary/ intervention). These aspects reflect the need for clinical inspection to support decision-making, as presence of cavitation and lesion activity may be assessed more accurately. Also, the lack of a well-defined criteria available for the radiographic assessment of restorations may have contributed to the differences found.

The experts of this study work as cariologists in university centers of reference, which may imply a more conservative position, widely supported by current scientific evidence where the intervention of defective restorations should be the last resort, preferring less invasive approaches, such as monitoring, refurbishment and repair [9]. A less conservative conduct by GDPs has already been reported in a series of studies [8,10], and it is suggested that the differences depend on clinical experience [12], and vary between GDPs and professionals with expertise or those involved in the university environment, such as graduate programs [32,33].

It is important to highlight that the bitewing radiographic assessment is a complementary exam to the clinical inspection, and it is often a necessary tool for the diagnosis of secondary caries, due to the cervical occurrence [34]. However, some factors should be considered in the radiographic interpretation for the treatment decision. The presence or absence of cavity is not predicted by the radiographs [2], and the detection of marginal gaps may result in false-positive and false-negative decisions [4]. In addition, it has already been showed that the presence of adhesive under the restoration can negatively influence the decision to intervene in the restoration [35,36]. Dental materials with low radiopacity may be misinterpreted as secondary caries [5]. These factors may lead dentists to unnecessary interventions.

In our study, intraexaminer reliability values ranged in general from moderate to excellent, showing consistency in the decision made by the experts, and it was higher than interexaminer reliability, as also reported by a previous study [37]. The agreement among experts varied from 0.07 to 0.64 according to the different conditions detected. As mentioned before, the 3 experts of this study are from distinct university environments, and have different clinical backgrounds, which can influence the level of agreement between them [38], even with previous training. The detection of overhang was the condition of greater agreement between experts, perhaps because it is easier to detect as it was also shown in a previous study [4]. Residual caries showed the worst level of agreement, which is justified since the radiographic appearance of residual caries may be resembling other conditions as secondary caries, improper adaptation etc.

The moderate agreement (kappa = 0.46) between GDPs and experts for the detection of secondary caries is positive and may signal that dentists are conducting a correct diagnosis of caries lesions around restorations, which has been widely discussed nowadays. Still, it seems important to note that even experts seem to agree less with each other regarding secondary caries detection than as a group (majority) compared to GDPs. Higher variation in the kappa values among each dentist and experts was found for the indication of intervention. And although it has been perceived an increase in most of the kappa values in the comparison between the treatment indication among GDPs and majority of experts when analyzing the cases designated as 'more information is necessary for treatment decision' by the majority of experts as 'intervention' compared to the analysis where the same cases were considered as 'non-intervention', the variation was maintained with fair agreement for the total number of cases.

However, the amount of secondary caries lesions that were found in this study and diagnosed by the GDPs indicates that in contrast to what often is speculated, GDPs diagnose often secondary caries lesions correctly. That secondary caries is not often found in clinical longevity studies, especially in controlled trials [22], therefore is likely more related to the different risk profiles of the investigated populations. Especially for restorative longevity studies often low risk patients are selected while caries and secondary caries is likely more present in a high caries risk population as investigated in the present study.

5.5 | **Conclusions**

In conclusion, GDPs and experts show moderate agreement for the detection of secondary caries and fair agreement to the treatment decision. The GDPs tend to have a less conservative approach regarding the decision to intervene or not.

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6

CHAPTER 6

Impact of individual-risk factors on caries treatment performed by general dental practitioners

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Abstract

Objective This prospective study investigated how individual patient risk factors impacted non-operative and operative treatment decisions in a dental practice-based research network in The Netherlands.

Methods Data from were collected from 11 dental practices, whose patients visited the practice at least once during the observation period (January 2015 to September 2017). Descriptive analysis was performed, followed by multiple logistic regression.

Results The records of 39,690 patients were analyzed. Approximately one-half of the population (n=21,056) underwent a restoration procedure during the observation period, of which 5981 (28.4%) were classified with fair oral hygiene, and 5341 (25.4%) with a high risk for caries. The population without restorative intervention (n=18,634) consisted mainly of patients with good oral health (n=5132 [27.5%]) and low risk for caries (n=7792 [41.8%]). A high risk for caries was associated with a greater chance of preventive instruction (odds ratio [OR] 1.60), applications of topical fluoride (OR 1.20) or sealants (OR 1.39), and restorative interventions (OR 5.72). There was wide variation among practices regarding the treatment provided.

Conclusion Of the 11 general dental practices that participated in this study, there was a higher chance of patients with a high risk for caries to receive preventive instructions, and professionally applied topical fluoride and sealants in the majority of practices promoting a personalized treatment approach to patients with caries.

Clinical significance
A more personalized treatment approach for patients with caries was associated with a higher prevalence of high caries risk patients in the majority of practices. More studies, however, are needed to investigate whether general dental practitioners consider the assessment of individual patient risk factors in planning personalized treatment strategies.

6.1 | Introduction

A recent review reported primary caries as the main reason for placement of restorations, ranging from 48.8% to 100% of cases, and secondary caries for restoration replacement (28.5–59%) [1]. Dental caries remain the most common disease in dentistry, and inequalities are observed in disease distribution, mainly related to factors including age and socioeconomic status (SES) [2]. These inequalities support the need to identify individuals who are at high risk for development the disease given that diagnostic and management strategies should be guided and implemented according to individual patient risk factors [3]. Age, SES, oral hygiene (presence of dental biofilm) are examples of risk factors that have already been associated directly or indirectly with the development of dental caries [2,4,5]. For this reason, these factors are usually used to determine caries risk in patients [6].

Thus, it appears logical that when general dental practitioners (GDPs) encounter these risk factors in patients and use them in clinical decision making, the result will be better and more personalized oral healthcare. Moreover, using risk factors to plan individual treatment strategies may improve the effectiveness of care and reduce treatment costs [3], thus enabling efficient allocation of resources in terms of government policies. The assessment of caries risk, for example, enables individualized treatment planning [7], based on strategies that can range from non-operative treatments, such as biofilm control and fluoride application, to operative treatments such as tooth restoration. Nevertheless, despite recommendations for less-invasive treatment [8], it has been reported that traditional approaches, based on "drill and fill" and "one-size-fits-all" methods, remains dominant among dentists [9].

It remains unknown to what degree GDPs use patient risk factors in their clinical decision making process. Given that dentists would need to devote more clinical time to risk assessment planning and individualized treatment, this could imply an increase in the costs of dental visits, especially for high-risk patients, due to shorter recall intervals and more preventive treatments, at least in the short term. It would then be expected that risk assessment would determine the type and frequency of interventions, especially in patients with high risk for caries. Therefore, the primary aim of this study was to investigate the association between individual patient risk factors and non-operative and operative treatment decisions among 11 general dental practices whose clinicians were members of a dental practice-based research network in The Netherlands.

The secondary aim was to describe the risk profile of the population attending the practice-based research network related to their need for restorative treatment.

6.2 | Materials and Methods

6.2.1 | Study design

This was a prospective single-blinded (the statistician) study based on data from a dental practice-based research network in The Netherlands. Data were collected from 11 dental practices. Descriptive analysis was performed, followed by multiple logistic regression. The primary outcome investigated was the association between patient risk factors and type of clinical approach. The secondary outcome was the treatment profiles of patients with and without restorative treatment during the study period. Ethics approval was granted by the local Ethics Committee, METC (CMO file no. 2015-1565).

6.2.2 | Study population

Eleven dental general practices were recruited from the dental practice-based research network in 2015 to participate in this study with anonymized data from electronic patient files (EPF). The sample included two solo practices, seven small group practices (two to three dentists), and two larger group practices (> 3 dentists). Four practices were located in rural areas, and 7 in urban areas (> 40,000 inhabitants). The population attending these practices was investigated. To be considered eligible for inclusion, patients were required to have visited the practice at least once during the observation period, between January 2015 and September 2017.

6.2.3 | Data extraction

All practices had the same EPF software system (Exquise1, Vertimart, Kwadijk, NL); data from patients attending the practices were collected digitally and anonymously transferred to a spreadsheet (Excel, Microsoft Corporation, Redmond, WA, USA) by the software company.

6.2.4 | Variables of interest

The following patient-related variables were collected for analysis: practice the patient was attending; sex; age; and general health based on the American Society of Anesthesiologists (ASA) physical status classification system. SES scores, based on the level of education and income of the district the patient resided (i.e., ZIP code), were provided by the Dutch Ministry of Public health, Welfare and Sports. Patients were ranked and divided into one of three groups: low, medium, and high SES. Specific patient-related factors were considered and assessed, and are described below:

Oral hygiene: This was assessed as good, fair or poor, and was classified by the GDPs based on the presence of plaque on the teeth. When more than one evaluation was performed during the observation period, the worst level of oral hygiene recorded for each patient was used.

Caries risk assessment: The risk for caries was assessed as high or low. A high risk for caries was attributed to patients by the GDPs based on the presence of the following: active lesions; number of new caries lesions (≥1 new caries lesions in the past year); number of restorations present; degree of self-care (insufficient plaque control); and frequent sugar consumption. Low risk was assigned to patients without active lesions and new caries lesions (last restoration due to caries ≥2 years previously), without or with few restorations, and sufficient plaque control. When risk assessment was performed more than once during the observation period, the worst level of caries risk was used.

6.2.5 | **Outcomes**

For each patient, all applied relevant dental treatments were registered from the EPFs including the total number of visits, preventive instruction consults, oral cleaning sessions, professional topical fluoride application, sealant application, and restorations. For the patient group with restorations, the total number of restorations during the observation period was calculated, including the number of interventions and re-interventions on the same tooth.

6.2.6 | **Statistical analysis**

Descriptive statistics of the study population were calculated. Statistical analysis was performed using SPSS version 22.0 (IBM Corporation, Armonk, NY, USA) for Windows (Microsoft Corporation, Redmond, WA, USA). Logistic regression was used to determine the influence of the variables of interest (sex, age, SES, caries risk, oral hygiene and practice) on the outcome variables related to the clinical approach (preventive instructions, dental cleaning sessions, professional topical fluoride applications, sealants, restorations, and total number of visits). In this first model, the practices were also included as a variable because each one has particularities, which should considered in the analysis. For the statistical analysis, the significance level was set at 5%. Considering the large amount of data regarding caries risk and other risk factors not registered by the GDPs, a multiple imputation analysis was also executed. However, the results were virtually the same as those obtained originally, and the authors chose to give preference to the simplest technique and omit the imputation process.

In addition, as a second analysis, the same regression model described above, with the same variables of interest and outcome variables, was executed individually for the population of each practice, resulting in 11 logistic regressions. However, only the odds ratio (OR) regarding caries risk – the main variable of interest – are shown. These data were retrieved from the regression analyses and presented in a table according to each practice (Table 3).

6.3 | **Results**

The records of 39,690 patients were included in the analysis. Table 1 presents the characterization of the population profile according to the performed interventions during the observation period. More than one-half of the population (21,056 patients) received a restoration. The older the population, the more patients received restorations: from 34% of patients (n = 2176) in the age group 5–15 years, up to 63% in the group 46–65 years of age (n = 7545).

TABLE 1 | Demographic characteristics of the study population according to the group treated with restorative intervention and without restorative intervention (n = 39690).

	No restorative intervention n = 18634		**Restorative intervention n = 21056**	
Variable	**n**	**%**	**n**	**%**
Gender				
Male	8698	(46)	10243	(54)
Female	9936	(48)	10813	(52)
Age				
5 – 15 years	4283	(66)	2176	(34)
16 – 25 years	3222	(53)	2857	(47)
26 – 45 years	4620	(44)	5811	(56)
46 – 65 years	4478	(37)	7545	(63)
66 years and older	2031	(43)	2667	(57)
Socioeconomic status				
Low	7482	(46)	8739	(54)
Medium	4395	(46)	5214	(54)
High	6757	(49)	7103	(51)
General health				
ASA I	8317	(45)	10318	(55)
ASA II	2583	(40)	3945	(60)
ASA III	194	(35)	322	(65)
ASA IV	9	(38)	15	(62)
Not recorded	7531	(54)	6456	(46)
Oral hygiene				
Good	5132	(48)	5616	(52)
Fair	3476	(37)	5981	(63)
Poor	325	(30)	770	(70)
Not recorded	9701	(53)	8689	(47)
Caries risk				
Low	7792	(52)	7067	(48)
High	1142	(19)	5341	(81)
Not recorded	9700	(53)	8648	(47)

Considering risk factors and their association with restorative treatment, general health status was assessed in 25,703 (65%) cases, with most patients exhibiting good general health (ASA I, n = 18,635 [73%]). A higher number of patients with ASA II (n = 3945 [60%]) and ASA III (n = 322 [65%]) underwent a restorative intervention, compared with the healthy (n = 10,318 [ASA I, 55%]) group. Oral hygiene was assessed in 21,300 patients, of whom the majority exhibited good oral hygiene (n = 10,748 [50%]), while 9457 (44%) had fair and 1095 (5%) exhibited poor oral hygiene. Of the group with good oral hygiene 52% (n = 5616) received a restoration while this number increased to 63% (n = 5981) and 70% (n = 770) for fair and poor oral hygiene, respectively. Caries risk was assessed in 21,342 (53.77%) of the patients, with 6483 (16.33%) recorded as having high and 14,859 (37.44%) having a low risk for caries. Of the patients with high risk, 5341 (81%) received a restoration, while 7067 (48%) were in the low risk group.

Regarding the restorative intervention group, a total of 68,740 restorations were placed during the observation period. The primary reasons for intervention included primary (n = 21,119 [30.7%]) and secondary (n = 12,729 [18.5%]) caries. Restorations to address primary and secondary caries were distributed according to age group, as presented in Figure 1. In the patients classified as low risk, 33.6% of 19,981 restorations were performed due to caries (primary caries, n = 3926 [19.6%]; secondary caries, n = 2792 [14.0%]), while 63.9% from the total of 22,910 restorations performed on the high caries risk group was attributed to caries detection (primary caries, n = 9244 [40.3%]; secondary caries, n = 5402 [23.6%]).

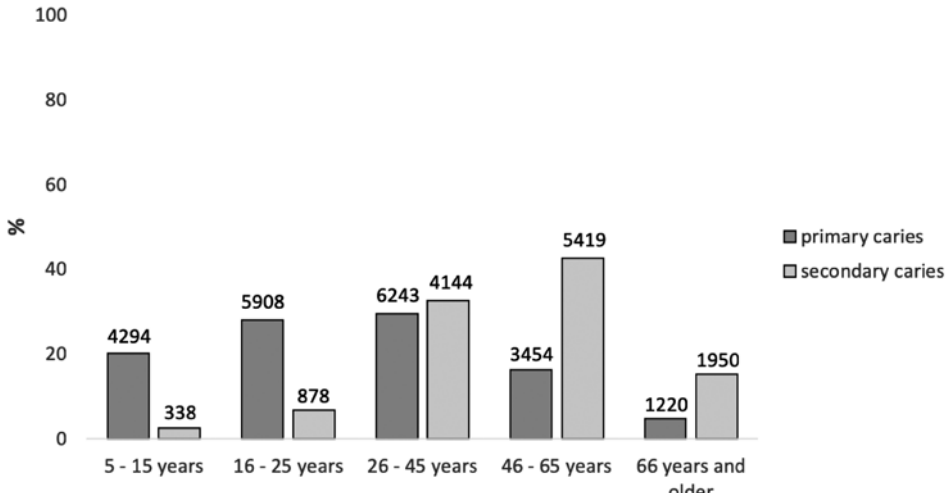

FIGURE 1 | Distribution of the restorations due to primary (n = 21,119) and secondary caries (n = 12,729) according to age groups in the population.

TABLE 2 | Logistic regression analysis of the characteristics and risk factors of patients according to the clinical approach related to non-operative and operative procedures.

	Prevention		Dental cleaning		Fluoride		Sealants		Restorations		Number of visits during observational period			
											up to 3 visits		more than 3 visits	
Variables	OR	Sig.	OR	Sig.	OR	Sig.	OR	Sig.	OR	Sig.	OR	Sig.	OR	Sig.
Gender (ref.: male)	1.05	0.33	0.90	0.01	0.98	0.76	1.18	0.02	1.01	0.81	0.84	0.00	1.19	0.00
Age (ref.: 5 – 15 y)		0.00		0.00		0.00		0.00		0.00		0.00		0.00
16 - 25 years	0.35	0.00	6.48	0.00	0.08	0.00	0.23	0.00	1.74	0.00	2.31	0.00	0.43	0.00
26 - 45 years	0.12	0.00	5.76	0.00	0.00	0.00	0.02	0.00	2.67	0.00	2.51	0.00	0.40	0.00
46 - 65 years	0.07	0.00	3.46	0.00	0.00	0.00	0.00	0.00	4.83	0.00	1.75	0.00	0.57	0.00
66 or older	0.05	0.00	2.26	0.00	0.00	0.00	0.00	0.98	4.53	0.00	1.65	0.00	0.61	0.00
Socioeconomic status (ref.: low)		0.79		0.33		0.16		0.43		0.09				0.00
Medium	1.02	0.82	1.06	0.31	0.90	0.26	0.91	0.35	0.94	0.21	1.11	0.02	0.91	0.02
High	1.05	0.49	0.97	0.55	0.85	0.07	1.06	0.59	0.91	0.03	1.13	0.00	0.89	0.00
Caries risk	1.61	0.00	0.77	0.00	1.20	0.01	1.39	0.00	5.72	0.00	1.14	0.00	0.88	0.00
Oral hygiene (ref.: poor)		0.00		0.00		0.00		0.04		0.00				0.00
Good	0.40	0.00	0.92	0.36	0.59	0.00	0.68	0.01	0.76	0.00	1.29	0.00	0.77	0.00
Fair	0.48	0.00	1.16	0.11	0.67	0.00	0.69	0.02	1.01	0.94	1.14	0.06	0.88	0.06
Practices (ref.: practice 1)		0.00		0.00		0.00		0.00		0.00				0.00
Practice 2	0.96	0.74	0.18	0.00	11.17	0.00	9.06	0.00	1.02	0.75	0.76	0.00	1.32	0.00
Practice 3	10.42	0.00	1.15	0.32	11.45	0.00	19.65	0.00	0.55	0.00	2.61	0.00	0.38	0.00
Practice 4	1.17	0.47	0.63	0.01	5.98	0.00	2.61	0.12	4.73	0.00	1.61	0.00	0.62	0.00
Practice 5	6.42	0.00	0.36	0.00	6.24	0.00	12.16	0.00	5.95	0.00	2.70	0.00	0.37	0.00
Practice 6	1.81	0.00	0.51	0.00	6.08	0.00	3.74	0.00	3.23	0.00	2.56	0.00	0.39	0.00
Practice 7	1.04	0.80	0.65	0.00	3.23	0.00	3.07	0.02	1.36	0.00	3.16	0.00	0.32	0.00
Practice 8	0.03	0.00	0.00	0.00	51.34	0.00	1.75	0.22	0.62	0.00	1.42	0.00	0.71	0.00
Practice 9	1.64	0.00	0.17	0.00	0.77	0.44	1.44	0.41	1.02	0.78	1.73	0.00	0.58	0.00
Practice 10	0.57	0.00	1.10	0.45	37.78	0.00	3.27	0.00	1.10	0.14	1.92	0.00	0.52	0.00
Practice 11	0.74	0.03	0.10	0.00	14.49	0.00	4.67	0.00	1.02	0.77	1.83	0.00	0.55	0.00
Constant	0.49	0.00	6.45	0.00	0.38	0.01	0.06	0.00	0.06	0.00	0.19	0.00	5.40	0.00

The results of logistic regression analysis according to clinical approach are shown in Table 2. The ORs reveal that most preventive instructions were provided to the young age groups, as well as fluoride and sealant applications. Risks for restorative treatment increased with

age. A high risk for caries demonstrated a significant association with greater chance for receiving preventive instruction (OR 1.61; p = 0.001), topical fluoride application (OR 1.20; p = 0.013), sealants (OR 1.39; p < 0.001) and restorations (OR 5.72; p < 0.001). High-risk patients had a chance of 1.14 of undergoing up to 3 visits during the observational period. Patients with good/fair oral hygiene were less likely to receive preventive instruction (OR 0.40; p = 0.001/OR 0.48; p < 0.001), topical fluoride application (OR 0.59; p < 0.001/OR 0.67; p = 0.003) and sealants (OR 0.68; p = 0.011/OR 0.69; p = 0.015) than patients with poor oral hygiene.

The odds of high caries risk patients receiving non-operative and operative procedures (compared with low-risk patients) in each practice separately are shown in Tables 3a and 3b. A wide variation is evident between practices regarding the treatment applied to high caries risk patients. The chance of high caries risk patients to receive preventive instruction and professional topical fluoride was higher compared with low-risk patients in the majority of practices, although the higher chance for topical fluoride was statistically significant for only 4 practices. The chance of high-risk patients receiving sealants was significantly higher in only 3 practices.

TABLE 3a | Odds ratio of caries risk patients' dental visits according to each practice.

	Preventive instruction visits				**Total number of visits**							
					up to 3 visits				**More than 3 visits**			
Practice	HR	LR	OR	Sig	HR	LR	OR	Sig	HR	LR	OR	Sig
1	48	65	1.8	0.01	219	491	1.5	0.00	314	1045	0.7	0.00
2	89	174	1.7	0.00	234	759	0.9	0.39	625	1934	1.1	0.39
3	408	411	1.5	0.00	488	619	0.5	0.00	452	365	2.1	0.00
4	23	12	2.2	0.05	86	155	0.7	0.05	121	161	1.5	0.05
5	238	66	1.6	0.01	350	143	1.3	0.14	230	118	0.8	0.14
6	112	136	1.6	0.00	375	590	1.2	0.09	259	509	0.8	0.09
7	12	60	1.1	0.80	98	718	1.1	0.56	73	448	0.9	0.56
8	0	4	0.0	0.99	125	452	1.5	0.00	133	681	0.7	0.00
9	75	124	1.3	0.13	210	519	1.2	0.18	221	662	0.8	0.18
10	72	151	1.4	0.04	399	1122	1.2	0.03	403	1371	0.8	0.03
11	165	167	2.2	0.00	551	800	1.5	0.00	517	1197	0.7	0.00
total	1242	1370			3135	6368			3348	8491		

Note: Odds ratio retrieved from logistic regression analysis. The following variables were considered in the analysis: gender, age, socioeconomic status, caries risk and oral hygiene. Only the impact of caries risk factor is shown in the table.
HR = number of high risk patients registered performing dental visits.
LR = number of low risk patients registered performing dental visits.
*reference group: low caries risk.

TABLE 3b | Odds ratio of caries risk patients receiving procedures according to each practice.

	Dental cleaning				Professional topical fluoride				Sealants				Restorations			
Practice	HR	LR	OR	Sig.	HR	LR	OR	Sig.	HR	LR	OR	Sig.	HR	LR	OR	Sig.
1	486	1458	0.6	0.01	11	2	12.8	0.00	2	5	0.5	0.44	433	781	5.0	0.00
2	599	1936	0.8	0.02	96	305	1.2	0.43	50	167	1.0	0.90	686	1209	5.3	0.00
3	892	909	1.7	0.01	95	176	2.0	0.01	84	149	1.5	0.07	712	241	9.0	0.00
4	190	287	1.6	0.21	12	4	1.6	0.52	3	2	0.9	0.88	198	258	9.6	0.00
5	492	218	1.2	0.52	88	2	16.6	0.00	73	8	1.1	0.83	559	212	8.5	0.00
6	525	998	0.5	0.00	48	110	0.7	0.15	30	32	2.0	0.03	593	774	5.7	0.00
7	155	1061	0.8	0.34	6	31	1.1	0.84	3	14	1.6	0.53	163	631	17.9	0.00
8	16	74	1.1	0.85	56	179	1.4	0.20	6	12	1.7	0.35	189	416	5.5	0.00
9	298	846	0.7	0.03	32	8	13.4	0.00	12	12	2.7	0.03	361	541	6.9	0.00
10	721	2344	0.6	0.01	193	692	0.7	0.02	39	106	1.3	0.17	642	1160	4.6	0.00
11	604	1143	0.9	0.09	293	553	1.1	0.664	112	141	1.5	0.01	805	844	5.21	0.00
total	4978	11274			930	2062			414	648			5341	7067		

Note: Odds ratio retrieved from logistic regression analysis. The following variables were considered in the analysis: gender, age, socioeconomic status, caries risk and oral hygiene. Only the impact of caries risk factor is shown in the table.
HR = number of high risk patients registered receiving the respective procedure.
LR = number of low risk patients registered receiving the respective procedure.
**reference group: low caries risk.*

6.4 | **Discussion**

This practice-based cohort study investigated the patient population of a group of general dental practices in the Netherlands, and compared profiles of patients receiving restorative treatment with those who did not. In addition, the effect of patient risk profile on the applied treatment protocols was analyzed. To our knowledge, this was the first study to analyze the patient population of a group of practices in this manner, based on EPFs and including the entire population attending the practices during the observation period. However, this study had some limitations. Although dentists were engaged in the project and stimulated to collect data into the EPFs during the observation period, a large amount of missing data – primarily related to risk assessments – was revealed. This factor was considered in the data analysis, and an imputation process for missing data was used; however, the outcomes were not affected. The present study demonstrated that extensive record keeping, which is essential in contemporary personalized care, remains a challenge for dentists in their daily routine. The practice sample size was also a limitation of our study; more specifically, it was too small to generalize the results, and should be considered as a special selection of practices related to the practice-based research network.

Another limitation of the study is that the caries risk assessment was performed once in some cases and, in other cases, more than once, in which the worst score was considered. However, it is reported in the literature [10] – as it was observed in our data – that in general, patient risk for caries at baseline and after the follow-up periods usually remains the same. Another limitation to the risk assessment is that it was based on the clinical judgement of one dentist and, therefore, it should be realized that the division of patients into high and low caries risk are likely based on the different thresholds of each GDP. The classification regarding oral hygiene of the patient in terms of good, fair and poor, may also be influenced by this factor.

Results of this study demonstrate that, over an interval of 2 years and 9 months, more than one-half of the patient population received a restorative treatment. There are no data regarding this finding available in other studies; nevertheless, our perception is that > 50% of a population receiving a restorative treatment in such a relatively short period is a considerable number. We performed two analyses on the results, one regression to show which treatment strategy was chosen related to patient characteristics and risk factors, and another regression focused on the caries risk assessment performed by different dentists and the way they adjusted their treatment to the higher or lower caries risk.

The population that did not receive a restorative intervention during the observation period consisted mostly of patients with good oral health and low risk for caries. In contrast, the group that underwent restorative intervention was characterized mainly by fair oral hygiene and high risk for caries, which is consistent with a previous study reporting higher

development of primary and secondary caries lesions in high caries risk patients compared with low caries risk [5], resulting in greater need for restorative intervention. In our study, patients 46 to 65 years of age had the highest chance for restorative interventions during the observational period, which may be explained by the progressive and linear increase in caries that occurs throughout life [11]. Moreover, it corresponds to the generation with late access to fluoride, given that fluoride was introduced for prevention of dental caries in the 1950s [12] and, in the Netherlands, fluoride content in drinking water is low, while from the late 70s onward, most commercially available toothpastes contained fluoride. As a result, this age group had a history of active caries in their youth, leading to considerable damage and restorative work, which requires maintenance and replacement during a lifetime. This also explains the higher number of restorations placed due to secondary caries compared with primary caries in this age group. Our study also demonstrated that in patients ≥ 66 years of age, the chance for restorative intervention decreases again, probably due to a reduced demand for restorative dental care attributed to tooth loss, decreased motivation for oral health care, and use of dental prostheses [13].

For patients with lower SES, the chance to receive a restoration was higher. SES has been reported to be strongly associated with dental treatment needs [14–16]. Additionally, for patients with general health problems, indicated by ASA II and III classifications, a higher chance for restorative intervention was observed. Oral health usually reflects general health [17], and systemic diseases may decrease the motivation for oral health care maintenance, resulting in a higher risk for caries [18], and also influenced by the effects caused by disease and medications [19].

From this we conclude that in the practices investigated, restorative work was performed in an important proportion of the high-risk group. In recent years, it has been demonstrated that patient-related factors play an important role in restorative treatment prognosis [20], and age, caries risk, parafunctional habits, and SES influence the success of restorative treatment [15,20–24]. Furthermore, it is often suggested that higher failure rates by practitioners are caused by operator failures or misdiagnosis; however, it is important to realize that the population in which practitioners place their restorations is mainly a high-risk population.

In our first logistic regression, we also investigated how patient factors impacted the clinical approach. Younger patients (5-15 years of age) were more likely to receive preventive instruction visits, fluoride, and sealants [25]. This may be due to extra attention provided by practitioners for this age group because it is the period of eruption of permanent teeth, which requires more attention to plaque control, and also because dietary habits in this age group often changes in this period [26]. In the Netherlands, these preventive treatments are reimbursed by public health until patients are 18 years of age, which may also explain the findings. Older patients had a higher odds of undergoing dental cleaning, which may be related to the onset of periodontal disease later in life.

In the second analysis, we investigated the role the caries risk assessment played in decision making. We found that caries risk was associated with higher chance of the patient receiving preventive instruction, topical fluoride application, and sealants and restorations, and a higher chance of the patient requiring up to 3 visits to the dental office during the observational period. This indicates that risk evaluation was used to guide treatment decisions. Although a wide variation among practices regarding the treatment applied to high caries risk patients was observed, it appears that some type of individualized, risk-oriented care was applied by the practices.

Notwithstanding the statistically significant associations, the odds of preventive procedures in high caries risk patients, compared with those in low-risk patients, still appears to be rather low. Moreover, low-risk patients, who theoretically would not require prevention procedures, such as professional application of fluoride and sealants, are also undergoing these measures, especially young children. Performing these treatments in low-risk children may be related to demands from concerned parents, but may also be promoted by financial stimulus because these treatments are reimbursed by the public health system. A previous study reported a low level of preventive measures for high-risk individuals, which was only slightly different in amount and type from that in individuals with low caries risk [5].

Regarding the practices evaluated, significant differences in performing non-operative and operative procedures were observed. This may be related to factors such as the location of the practices in different areas (urban or rural), size of each practice (solo, small, or large) and to the populations attending the practices (i.e., younger or older patients). However, it may also reflect the personal attitude of the dentist in promoting or not promoting the concept of individualized care [27].

Finally, it appears that a restorative focus on caries treatment remains dominant, notwithstanding the scientific evidence supporting less invasive therapies [8]; in the present study, patients with high risk for caries were more likely to receive operative rather than non-operative treatment. It has been suggested that dentists do not trust patients to control caries lesions with self-directed preventive measures and, instead, trust the effect of restorative treatment [5,28].

In conclusion, a high caries risk was associated with higher chance of the patient receiving preventive instruction, application of topical fluoride, and sealants and restorations. Although it appears that individualized treatment is being applied by some practices, further investigations are needed to examine whether the GDPs are, in fact, using risk assessment to plan individual treatment strategies.

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7

CHAPTER 7

General discussion and conclusions

7.1 | General Discussion

Clinical diagnosis and decision-making in dentistry remains a challenge, even after many years of research and discussion. Regarding caries, there has been a considerable variation among dentists when it comes to the diagnosis and management of primary caries, and these differences seem only to increase when secondary caries are evaluated. Such differences, which are the result of the various approaches in decision-making regarding repairing or replacing restorations, have promote debates about what it would be considered a clinically acceptable restoration. Moreover, it is unclear to what extent clinical decisions made by General Dental Practitioners (GDPs) are influenced by the patients' individual risk factors. This thesis addressed some of those issues, and its findings will be discussed below.

7.1.1 | Assessment of restorations and secondary caries

Several studies have mentioned the remarkable differences between clinicians related to the diagnosis of caries around restorations, which were also observed in this thesis. These differences are probably associated with the misinterpretation of marginal defects and staining around the restoration, with secondary caries. For example, the probe can stick in overhangs suggesting secondary caries [1], and also, black and brown marginal staining can be misinterpreted as initial lesions. These aspects, as the presence of marginal ditching, staining, discoloration of the dental tissues and gaps at the tooth restoration interface, have already been subject of research, and showed to be unreliable predictors of caries around the restorations [2–5]. Still, the misdiagnosis of marginal defects as caries lesions reflects the lack of understanding of the factors associated with the development of caries lesions around the restorations in the clinical practice.

Although some studies claim that the inconsistency in decision-making on restorations among dentists is due to the variability of the available criteria and lack of a standard approach, no study had so far summarized the existing criteria used for the diagnosis of dental caries around restorations, to support this claim. Thus, this was performed in the systematic review in Chapter 2. Substantial variability in the criteria used for the diagnosis of caries around restorations was indeed observed, which is not helpful for a common understanding of the caries-diagnostic process and clinical decision-making [6]. This helps to explain the variation found between clinicians in Chapters 4 and 5, and probably it also influences in some level the differences found among practices in Chapter 6. Moreover, neither of the studies included in our review used a criterion covering all three aspects (systematization of the criterion, lesion activity assessment and differential diagnosis) considered by us as essential for a good caries diagnostic technique.

In addition, we need to recognize that there is a considerable level of subjectivity in the clinical diagnosis process, even when decision-making is based on scoring systems,

such as CARS (Caries Associated with Restorations and Sealants) criteria from ICCMS (The International Caries Classification and Management System) [7], used in Chapter 3, or FDI (FDI World Dental Federation) criteria [8], used in Chapter 4. Their criteria are open to interpretation, even among experienced clinicians, depending on whether they are more or less conservative [9].

Differences in the assessment were observed even among experts in Chapter 5 regarding the detection of secondary caries, lack of material, adaptation and presence of overhang. A factor that may influence the variation among experts, even whether submitted to previous training, is their clinical background [10], and the fact that they are from different university environments. The lack of broadly accepted and disseminated diagnostic criteria for radiographic diagnosis as reported in Chapter 2, may also have played a role. Only one study was identified, which reported the use of a systematized criterion and inferred differential diagnosis between the radiolucent image of caries from other defects [11]. This factor is probably also responsible for the moderate agreement found between GDPs and experts related to the detection of secondary caries (Chapter 5). However, the level of agreement was considered to be acceptable, considering the limitation of the study design that did not allow the clinical evaluation by the experts.

Differences in the diagnosis of restorations between dentists in clinical practice reflect the disparities that characterize teaching in dentistry [12]. Actions need to be employed during the graduation to develop competencies of the future professionals [13]. So, more than just showing evidence of the problem, we looked for ways to tackle the issue. An interesting tool for teaching students is the use of complementary educational strategies [14–16]. The implementation of a training workshop additionally to the lecture showed an improvement in the diagnostic performance of the students, which is in agreement with previous studies [15,17,18]. It also increased knowledge retention, which was similarly reported by previous studies using different methodologies [19,20].

The choice of the system used for detection of caries in the training in Chapter 3 was based in the findings of Chapter 2, that showed the Caries Associated with Restorations and Sealants (CARS) criteria as the more suitable one for the visual inspection, as not only the diagnosis of the severity of the lesion is described, but also aspects such as stained margins and amalgam shadows, that are not consistent with caries lesions, and the presence or absence of demineralization around a defective restoration are taken into account [7]. In addition, we used the available knowledge about the *in vitro* induction of secondary caries lesions in the literature to create artificial caries-like lesions with whitish opaque and rough enamel, and soft dentin, which can be considered a useful tool in the development of the skills of the students.

In Practice Based Research, looking at day by day decisions made by general practitioners, variation in the diagnostic practices is an important consideration. Practitioners without

previous training in diagnosis, treatment and assessment of restorations may introduce a bias in the dental research [21], depending of the aim of the research, due to the variability in the assessment of the restorations related to the perception about what is a failure and what is an acceptable restorative defect. The assessment of digital photography performed by intraoral camera showed to be a useful indirect diagnostic method for the evaluation of dental restorations, mainly in posterior teeth (Chapter 4). It is a possible tool to the evaluation of restorations quality, reducing the risk of bias. The purpose would be that general dental practitioners take the photograph in their clinical practice and send it to independent investigators for assessment. For instance, the use of digital photography would help to interpret better the findings of Chapter 5 and 6.

However, although the method has shown good accuracy (84.8%), and compatible results with the visual detection method as reported by previous studies [22–24], it should be employed taking into account the higher detection of defects provided by the images [25–28] compared to the clinical assessment. Such defects are not always clinically relevant, it thus carries a risk of over-diagnosis. In addition, differences regarding the detection of restorations failures, mainly for anterior teeth, were shown in the assessment. The analysis of anterior restorations add the aesthetic component, that may result in increase of differences in the detection of defects. The perception of aesthetics is subjective and varies between individuals depending on the educational level, age and environment [29], and this reduces the consistency between different examiners.

Likewise, we also analyzed in the systematic review (Chapter 2) whether the studies included about diagnosis (accuracy) associate the diagnostic criteria and outcomes collected to the treatment decision for patients, since, in the end, the best diagnostic criteria are the ones that result in the best oral health outcomes to the patient [6]. Thus, the diagnostic decision should not be viewed as a completely separate step from the treatment decision, as it is the resulting treatment that matters if we think about optimal patient outcomes. What was observed is that the majority of studies showed lack of clinical relevance, that is, did not address the clinical implications of the diagnosis based on different criteria and thresholds to the treatment decision. Also, no study investigated patient-centered outcomes, which illustrates the existing gap between caries diagnostic research efforts and improvement of patients' oral health [6,30].

7.1.2 | Decision-making

Practice based research networks are useful to the understanding of how general dental practitioners are diagnosing and managing patients in clinical practice. In Chapter 5, looking closely at the decision-making of general practitioners on interventions at restorations, it was shown that GDPs appeared to have a less conservative approach regarding the decision to intervene or not compared to experts. A less conservative conduct by GDPs has already been reported in a series of studies [31,32], and it is suggested that

the differences are influenced by the clinical experience [33]. The experts of the study work as cariologists in university centers of reference, which may imply a more conservative position, supported by the current scientific evidence which claim that the intervention of a defective restoration should be the last resort [9]. The differences between GDPs and professionals with expertise or those involved in the university environment were already reported by previous studies [34,35]. However, as mentioned before, these findings may also be related to the fact that the experts were not able to do a clinical examination of the cases.

Treatment decisions are influenced by two main aspects: the dentist and the factors related to the patient [6]. The factors related to the dentist can be divided into three areas: personal characteristics (age/experience, tolerance for uncertainty, knowledge), biases (restoration utility, treatment preferences, diagnostic techniques) and practice characteristics (busyness, personnel, guidelines). Although in Chapter 5 and 6 we did not explore specifically these factors, they probably have played a role in the quite substantial differences in the performance of non-operative or operative procedures on the patients observed in Chapter 6. Practice characteristics that may played a role were: area of location, size of the practice and type of population attending to the practice. In addition, we hypothesized that the personal attitude of the dentist in following or not the approach of individualized care may also have influenced the findings. Still, further studies need to be conducted to examine the influence of the specific factors related to the dentist on the treatment decision.

Patient factors that impact on decision-making and prognosis can roughly be divided into three levels: tooth level (visual, tactile or radiographic signs), mouth level (caries status, oral hygiene) and patient level (diet, fluoride exposure, medications, disease, socio-economic status, insurance). In Chapter 6 we observed that the profile of the population that was submitted to a restorative intervention was characterized mainly by fair oral hygiene and high caries risk. We also found a higher chance for high caries risk patients receiving preventive instructions, professional topical fluoride and sealants in the majority of practices, suggesting a treatment approach based on the risk of caries of the patient. This finding may indicate that GDPs are in fact implementing diagnostic and management strategies according to individual patient risk factors, however, due to the limitations of the study design, further investigations are needed to examine whether the GDPs are in fact using the risk assessment to plan the patient's treatment.

In Chapter 6 we also observed that caries risk patients were much more likely to receive operative treatment than non-operative, which raised the question whether the traditional approach characterized as 'drill and fill' could be still prevalent among GDPs. However, the data does not allow us to draw a firm conclusion. Although it is supported by the less conservative trend of GDPs regarding the intervention on existing restorations observed in Chapter 5. There may be some way to go before general dental practice

completely adheres to the minimally invasive treatment approach [36], characterized by three principles [37]: avoid restoration placement as much as possible, place restorations for maximum longevity, and in case of need of re-intervention replacement should be the last alternative, preferring refurbishment or repair.

7.1.3 | How to improve diagnosis and decision-making in restorative dentistry?

First, there is a need for improvement of visual and radiographic diagnostic criteria used in the detection of caries around restorations in clinical practice, since an accurate detection of the lesion will contribute to a correct allocation of the treatment [38], avoiding overtreatment. It may not be realistic to think on the establishment and diffusion of a single system among dentists in order to reduce the differences observed in the decision-making process (Chapter 5), but the academy has been moving in this direction with the emergence of guidelines and consensus reporting. Also, this thesis calls attention to the need of critical thinking linking diagnosis and treatment decision, ensuring the best treatment for the patient (Chapter 2).

We investigated ways to improve the assessment of the restorations, to decrease the differences found among professionals, in two fields: clinical practice, using a training coupled with a lecture for the teaching of diagnosis and management of restorations (Chapter 3), and dental research, (Chapter 4) through the validation of the assessment of intraoral digital photography in the evaluation of dental restorations.

We consider that the education is at the core of the problem and it is the solution. And even so, there is only a small movement on the part of the researchers to look for ways to improve the education related to the management of restorations by professionals in dentistry. We need to think about how to disseminate the available knowledge for the dentists. The methodology studied in Chapter 3 might be used in a multicenter study, as a first step towards more uniform teaching of the subject. Modules of continuing education should be designed, possibly using the image-based approach studied in Chapter 4 to reach professionals in clinical practice. Possibilities for peer feedback and quality control using intra-oral photographs should be explored.

Finally, this thesis emphasizes the importance of the patient in treatment decisions. There is a clear need for more studies investigating patient centred outcomes.

7.2 | Conclusions of this thesis

- The majority of accuracy studies on the visual and radiographic detection of secondary caries shows lack of clinical relevance.

- Substantial variability was observed in the criteria used for the detection of secondary caries.
- The employment of a hands-on workshop has a positive impact in the learning process about the diagnosis and management of restorations.
- Evaluation of digital photographs using an intraoral camera is an indirect diagnostic method valid for the assessment of dental restorations and it is especially useful for posterior teeth. However, the method results in the detection of more defects compared to the clinical assessment and care should be taken for clinical decision making based on intraoral images.
- GDPs and experts show moderate agreement for the detection of secondary caries and fair agreement for the treatment decision. The GDPs tend to have a less conservative approach regarding the decision to intervene or not.
- Caries risk was associated with higher chance of the patient receiving preventive instruction, topical fluoride application and sealants in the majority of practices, suggesting a personalized treatment approach for high caries risk patients. However, there was a wide variation between practices regarding the treatment provided.

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Summary

This PhD thesis is based on five studies that aimed to investigate the criteria used for the detection of secondary caries, restoration assessment and treatment decisions of dental professionals, alternatives to improve the diagnosis, and the impact of patient related factors on the dental treatment.

Chapter 1 describes the aspects related to the diagnosis of restorations and caries reviewing the factors that influence and could improve decision-making at restorations.

Chapter 2 presents a critical evaluation of the clinical relevance of accuracy studies on visual and radiographic methods for secondary caries detection through a systematic review. The systematization of the diagnostic criteria, lesion activity assessment and differential diagnosis of secondary caries from factors that can lead to misinterpretations were assessed. The clinical relevance of the studies was based on the presence of the following aspects: link to treatment decision, evaluation of patient-centered outcomes, establishment of thresholds for non-operative and operative treatment, lesion activity assessment, and the use of reference method. Nineteen articles were selected for revision. The studies showed the use of different diagnostic criteria, mainly regarding visual inspection. The use of a standardized diagnostic system, lesion activity assessment and differential diagnosis were described by a limited number of studies. Approximately half of the studies reported association of diagnosis and treatment. Enamel lesions were evaluated radiographically in 28.6% of the studies, and visually in 69.2% of them. Visual diagnosis was more relevant in relation to the operative treatment decision. Patient-centered outcomes were not investigated by these studies. The majority of studies failed to present clinical relevance and report of patient-centered outcomes.

In **Chapter 3** we investigated the impact of a workshop on the learning process of undergraduate students regarding their ability to diagnose and propose a treatment for the management of restorations. This was a randomized controlled study with two parallel-groups tested: lecture and lecture coupled with a diagnostic workshop. The students' theoretical knowledge, perception about the activity and practical abilities was assessed immediately after the intervention, and theoretical knowledge was reassessed 6 months later. Higher average scores were shown for the group of lecture coupled with a diagnostic workshop in the assignment of lesion severity and activity, presence of marginal defect and treatment indication. Multilevel regression showed a positive impact of the workshop diagnosis in the correct assessment of lesion activity. There was no statistical difference for students' perception of the activity. After 6 months, the group submitted to the additional training showed higher level of knowledge retention. In conclusion, the diagnostic workshop helped students in the process of diagnosis and management of restorations.

In **Chapter 4** we investigated the validity of intraoral digital photography in the assessment of dental restorations. Evaluations were performed by a gold standard evaluator and 3 trained dentists (consensus). The visual assessment was the method used as the gold standard. A higher prevalence of failed restorations was identified by the intraoral digital photography in comparison to the visual assessment. Moderate agreement in the diagnosis of total failures was shown between the methods. The diagnosis reached by the Gold standard and the consensus showed substantial and moderate agreement for posterior restorations, and fair and moderate agreement for anterior restorations, respectively. The accuracy reached in the restorations assessment was 84.8%, with a sensitivity of 78.6% and specificity of 85.9%. In conclusion, digital photography performed by intraoral camera is an indirect diagnostic method valid for the assessments of dental restorations, mainly in posterior teeth. This method should be employed taking into account the higher detection of defects provided by the images, which are not always clinically relevant.

In **Chapter 5** we compared decision-making based on bitewing analysis of restored proximal surfaces by General Dental Practitioners (GDPs) with diagnosis and clinical decisions made by three experts in cariology and restorative dentistry. Posterior bitewing radiographs were selected from the electronic patient files of patients from a practice based research network and 770 cases of proximal restored surfaces were elected. Half of the cases came from the decisions that resulted in restorative interventions and the other half from the decision to only monitor the surface. Agreement between GDPs and two or more experts regarding secondary caries diagnosis varied between 67% and 83%. In 173 out of 385 cases that were treated by GDPs were suggested to monitoring by the experts. The agreement between experts and GDPs was moderate for secondary caries detection, and fair for treatment decision. The GDPs tended to have a less conservative approach regarding the decision to intervene or not concerning the reassessment of restorations.

In **Chapter 6** we investigated in a prospective study how individual patient risk factors impact on non-operative and operative treatment decisions in a Dental Practice-Based Research Network in The Netherlands. Data were collected from 11 dental practices and the records of 39690 patients were analysed. Approximately half of the population received a restoration during the observation period, with a large number of patients with fair oral hygiene and high caries risk. High caries risk was associated with a greater chance of preventive instruction, topical fluoride application, sealants and restorations. There was a wide variation between practices regarding the treatment provided. A more personalized treatment approach can be identified by high caries risk patients receiving preventive instructions, professional topical fluoride and sealants in the majority of the practices.

Finally, in **Chapter 7** a general discussion of the thesis is provided.

Resumo

Essa tese de doutorado é baseada em cinco estudos que objetivaram investigar os critérios usados para a detecção de cárie secundária, avaliação de restaurações e decisões de tratamento de profissionais da odontologia, alternativas para melhorar o diagnóstico, e o impacto de fatores relacionados ao paciente no tratamento odontológico.

O **Capítulo 1** descreve os aspectos relacionados ao diagnóstico de restaurações e cárie dentária revisando os fatores que influenciam e poderiam melhorar a tomada de decisão sobre restaurações.

O **Capítulo 2** apresenta uma avaliação crítica da relevância clínica de estudos de acurácia sobre os métodos visual e radiográfico para a detecção de cárie secundária através de uma revisão sistemática. A sistematização dos critérios de diagnóstico, avaliação da atividade da lesão e diagnóstico diferencial de cárie secundária de fatores que podem levar a interpretações erradas foram avaliados. A relevância clínica dos estudos foi baseada na presença dos seguintes aspectos: associação com a decisão de tratamento, avaliação de desfechos centrados no paciente, estabelecimento de limites para o tratamento não-operatório e operatório, avaliação da atividade da lesão, e uso de método de referência. Dezenove artigos foram selecionados para revisão. Os estudos mostraram o uso de diferentes critérios de diagnóstico, principalmente relacionados com a inspeção visual. O uso de um sistema de diagnóstico padronizado, avaliação da atividade da lesão e diagnóstico diferencial foram descritos por um número limitado de estudos. Aproximadamente metade dos estudos reportaram associação do diagnóstico e tratamento. Lesões em esmalte foram avaliadas radiograficamente em 28.6% dos estudos, e visualmente em 69.2% deles. O diagnóstico visual foi mais relevante em relação à decisão de tratamento operatória. Desfechos centrados no paciente não foram investigados por esses estudos. A maioria dos estudos falhou em apresentar relevância clínica e reporte de desfechos centrados no paciente.

No **Capítulo 3** nós investigamos o impacto de uma oficina no processo de aprendizagem de estudantes de graduação sobre a habilidade para diagnosticar e propor um tratamento para o manejo de restaurações. Esse foi um estudo controlado randomizado com dois grupos paralelos testados: aula teórica e aula teórica associada com uma oficina de diagnóstico. O conhecimento teórico dos estudantes, percepção sobre a atividade e habilidades práticas foram avaliados imediatamente após a intervenção, e o conhecimento teórico foi reavaliado 6 meses depois. Uma média mais alta de pontuação foi demonstrada para o grupo de aula teórica associada com a oficina de diagnóstico na designação da severidade e atividade da lesão, presença de defeito marginal e indicação de tratamento. A regressão multinível mostrou um impacto positivo da oficina de diagnóstico na avaliação correta da atividade da lesão. Não houve diferença estatística significativa para a percepção dos

estudantes da atividade. Após 6 meses, o grupo submetido ao treinamento adicional mostrou maior nível de retenção de conhecimento. Em conclusão, a oficina de diagnóstico ajudou os estudantes no processo de diagnóstico e manejo de restaurações.

No **Capítulo 4** nós investigamos a validade da fotografia digital intra-oral na avaliação de restaurações dentárias. Avaliações foram realizadas por um examinador padrão-ouro e 3 examinadores treinados (consenso). A inspeção clínica foi o método padrão-ouro. Uma alta prevalência de restaurações com falhas foi identificada pela fotografia digital intra-oral em comparação com a avaliação visual. Moderada concordância no diagnóstico de falhas totais foi mostrada entre os métodos. O diagnóstico atingido pelo padrão-ouro e consenso mostrou concordância substancial e moderada para restaurações posteriores, e razoável e moderada concordância para restaurações anteriores, respectivamente. A acurácia alcançada na avaliação de restaurações foi 84.8%, com uma sensibilidade de 78.6% e especificidade de 85.9%. Em conclusão, a fotografia digital realizada por câmera intra-oral é um método de diagnóstico válido para a avaliação de restaurações dentárias, principalmente em dentes posteriores. Esse método deveria ser empregado levando em consideração a maior detecção de defeitos fornecida pelas imagens, que não são sempre clinicamente relevantes.

No **Capítulo 5** nós comparamos a tomada de decisão baseada na análise de radiografias interproximais de superfícies proximais restauradas por Clínicos Gerais de Odontologia (CGO) com o diagnóstico e decisão clínica realizados por três especialistas em cariologia e odontologia restauradora. Radiografias interproximais posteriores foram selecionadas de arquivos eletrônicos dos pacientes de uma rede de pesquisa baseada na prática clínica, e 770 casos de superfícies proximais restauradas foram selecionados. Metade dos casos vieram de decisões que resultaram em intervenções restauradoras e a outra metade da decisão de apenas monitorar a superfície. A concordância entre CGO e 2 ou mais especialistas em relação ao diagnóstico de cárie secundária variou entre 67% e 83%. Em 173 dos 385 casos que foram tratados pelos CGO foram sugeridos por monitoramento pelos especialistas. A concordância entre especialistas e CGO foi moderada para detecção de cárie secundária, e razoável para a decisão de tratamento. Os CGO tendem a ter uma abordagem menos conservadora em relação à decisão de intervir ou não em relação à reavaliação de restaurações.

No **Capítulo 6** nós investigamos em um estudo prospectivo como os fatores de risco individuais do paciente impactam nas decisões de tratamento operatórias e não-operatórias em uma rede de pesquisa baseada na prática clínica na Holanda. Os dados foram coletados de 11 clínicas odontológicas e os registros de 39690 foram analisados. Aproximadamente metade da população recebeu uma restauração durante o período de observação, com um amplo número de pacientes com higiene oral razoável e alto risco de cárie. Alto risco de cárie foi associado com maior chance de instrução de prevenção, aplicação tópica de flúor, selantes e restaurações. Houve uma ampla variação entre

as clínicas odontológicas relacionadas ao tratamento fornecido. Uma abordagem de tratamento mais personalizada pode ser identificada por pacientes com alto risco de cárie estarem recebendo instruções de prevenção, flúor tópico professional e selantes na maioria das práticas.

Finalmente, no **Capítulo 7** uma discussão geral da tese é fornecida.

Samenvatting

Dit proefschrift is gebaseerd op vijf studies waarin beoogd werd om de criteria voor de detectie van secundaire cariës, het gedrag van professionals in de tandheelkunde, alternatieven om de diagnose te verbeteren en de invloed van patiënt gerelateerde factoren op de tandheelkundige behandeling te onderzoeken.

Hoofdstuk 1 beschrijft de aspecten gerelateerd aan de diagnose van restauraties en cariës, waarbij de factoren die deze beslissing kunnen beïnvloeden worden besproken en hoe dit besluitvormingsproces rondom het vervangen van restauraties verbeterd kan worden.

Hoofdstuk 2 bestaat uit een kritische beschouwing over de klinische relevantie van nauwkeurigheidstudies betreffende visuele en radiografische methoden voor de detectie van secundaire cariës. Hierin werden beoordeeld hoe systematisch de diagnostische criteria waren, de beoordeling van laesie activiteit en de differentiële diagnose van secundaire cariës van factoren die kunnen leiden tot misinterpretaties. De klinische relevantie van de studies werd geëvalueerd door middel van het rapporteren van aspecten gerelateerd aan: link naar behandelbeslissing, evaluatie van patiënt-gecentreerde uitkomsten, vaststellen van drempelwaarden voor niet-operatieve en operatieve behandeling, beoordeling van laesie activiteit en referentiemethode. Negentien artikelen werden beoordeeld. Verschillende diagnostische criteria werden gerapporteerd, voornamelijk betreffende visuele inspectie. Het gebruik van een gestandaardiseerd diagnostisch systeem, beoordeling van laesie activiteit en differentiële diagnose werden slechts door een gelimiteerd aantal studies beschreven. Ongeveer de helft van de studies rapporteerden een associatie tussen de diagnose en de behandeling. Glazuurlaesies werden in 28,6% radiografisch en in 69,2% visueel geëvalueerd. De visuele beoordeling hield meer verband met de operatieve behandeling beslissing dan de radiografische beoordeling. Patiënt-gecentreerde uitkomsten werden niet onderzocht in deze studies. De meerderheid van de studies konden geen klinische relevantie aantonen en rapporteerden geen patiënt-gecentreerde uitkomsten.

In **Hoofdstuk 3** onderzochten we de impact van een workshop op het leerproces van bachelor studenten betreffende hun vermogen om restauraties te diagnosticeren en hiervoor een behandelingstrategie op te stellen. Dit was een gerandomiseerd en gecontroleerde studie waarin twee parallel groepen werden getoetst: alleen een hoorcollege en een hoorcollege in combinatie met een diagnostische workshop. De kennis, de perceptie over de activiteit en de praktische vaardigheden van de studenten werden direct na de interventie beoordeeld en de theoretische kennis werd 6 maanden later nogmaals beoordeeld. Hogere gemiddelde scores werden gezien in de groep die een hoorcollege in combinatie met de diagnostische workshop volgde, betreffende de toewijzing van laesie ernst en activiteit, aanwezigheid van marginale defecten en

behandelindicatie. Multilevel regressie toonde een positieve impact van de workshop op de juiste beoordeling van de laesie activiteit aan. Er was geen statistisch verschil voor de perceptie van de student op de activiteit. Na 6 maanden, liet de groep die een extra workshop had gevolgd, zien dat ze de kennis beter hadden onthouden. Concluderend, de diagnostische workshop had een positieve impact op het onderwijs- en leerproces van de diagnosestelling en management van restauraties.

In **Hoofdstuk 4** onderzochten we de validiteit van intra orale digitale fotografie in het beoordelen van tandheelkundige restauraties. Evaluaties werden uitgevoerd door een gouden standaard evaluator en 3 getrainde tandartsen (overeenstemming). Visuele inspectie werd als gouden standaard gezien. Met de intraorale, digitale fotografie werd een hogere prevalentie qua falende restauraties gevonden dan met de visuele inspectie. Er was gemiddelde overeenstemming in de diagnose van falende restauraties tussen de methoden.

De diagnose vastgesteld aan de hand van de gouden standaard en de overeenstemming toonden een substantiële en matige overeenkomst voor posterieure restauraties aan en een goede en matige overeenkomst voor anterieure restauraties. De gevonden nauwkeurigheid in de beoordeling van de restauraties was 84,8% met intra orale foto's. Sensitiviteit en specificiteit waarden van 87,5% en 89,3% werden gevonden. Concluderend, digitale fotografie met een intra orale camera is een indirecte diagnostische methode die toepasbaar is voor de beoordeling van tandheelkundige restauraties, voornamelijk in posterieure tanden. Bij het gebruik van deze methode moet rekening gehouden worden met de hogere detectie van defecten geleverd door de foto's, die niet altijd klinisch relevant zijn.

In **Hoofdstuk 5** vergeleken we de besluitvorming op basis van bitewing analyse van gerestaureerde approximale oppervlakken door algemeen praktiserende tandartsen, met de diagnose en besluitvorming van drie experts in de cariologie en restauratieve tandheelkunde. Posterieure bitewing röntgenfoto's werden geselecteerd uit de elektronische patiënten dossiers van een practice based research netwerk en 770 gevallen van approximaal gerestaureerde oppervlakken werden geselecteerd. De helft van de gevallen leidde tot restauratieve beslissingen en in de andere helft van de gevallen werd besloten om te monitoren. Overeenstemming tussen de algemene tandartsen en twee of meer van de experts betreffende de diagnose van secundaire cariës varieerde tussen 67% en 83%. 173 van de 385 gevallen die werden behandeld door de algemene tandartsen, zouden door de experts worden gemonitord. De overeenstemming tussen experts en algemene tandartsen was matig voor secundaire cariës detectie en goed voor behandelbeslissing. De algemene tandartsen neigden naar een minder behoudende aanpak bij de beslissing om in te grijpen en neigden minder vaak tot het herbeoordelen van restauraties.

In **Hoofdstuk 6** onderzochten we in een prospectieve studie hoe individuele patiënt risico factoren invloed hadden op niet-operatieve en operatieve behandelbeslissingen binnen een Practice based research Netwerk in Nederland. Data werden verzameld uit 11 tandheelkundige praktijken en de dossiers van 39.690 patiënten werden geanalyseerd. Ongeveer de helft van de populatie kregen een restauratie gedurende de observatieperiode, waarvan een groot aantal patiënten met goede mondhygiëne en hoog cariës risico. Hoog cariës risico werd geassocieerd met een grotere kans op preventieve instructie, fluoride applicatie, sealants en restauraties. Er was een grote variatie tussen praktijken met betrekking tot de uitgevoerde behandeling. Patiënten met een hoog cariës risico ontvingen in de meerderheid van de praktijken meer professionele fluoride applicatie en sealants, wat een gepersonaliseerde behandelaanpak voor patiënten met cariës suggereert.

Tot slot wordt in **Hoofdstuk 7** een algemene discussie over dit proefschrift gevoerd.

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Cácia Signori

Personal aspects

Cácia is Brazilian; she was born in Balneário Camboriú – SC, a lovely beach at south of Brazil. She is the youngest daughter of the loving and dedicated parents, *Domingos* and *Sônia*. She is a lucky girl to be part of the Signori and Rebelo families.

Professional aspects

Cácia is graduated in Dentistry (2012) at Federal University of Pelotas, RS, Brazil. She is Master of Dental Science (2015) at Federal University of Pelotas. She is very honoured to be a Joint PhD student at Radboud University Medical Center and Federal University of Pelotas during period of 2016 up to the present moment.

Interests

She loves research. She loves to teach. She loves to discover new places. She enjoys having a coffee with friends.

Contact

caciasignori@gmail.com
https://www.researchgate.net/profile/Cacia_Signori2