

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 predictive 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.

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

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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.

2. Materials and methods

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.

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 N° 1.468.455/2016), and participants have signed a written informed consent.

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].

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, color 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.

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 to 25 mm 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 1024 × 768 fixed image resolution. All images were registered and stored in a database. No image correction related to color, brightness, and contrast was performed. Fig. 1 shows examples of photographs used in the study for anterior and posterior restorations with and without failures.

2.6. 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.

2.7. 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

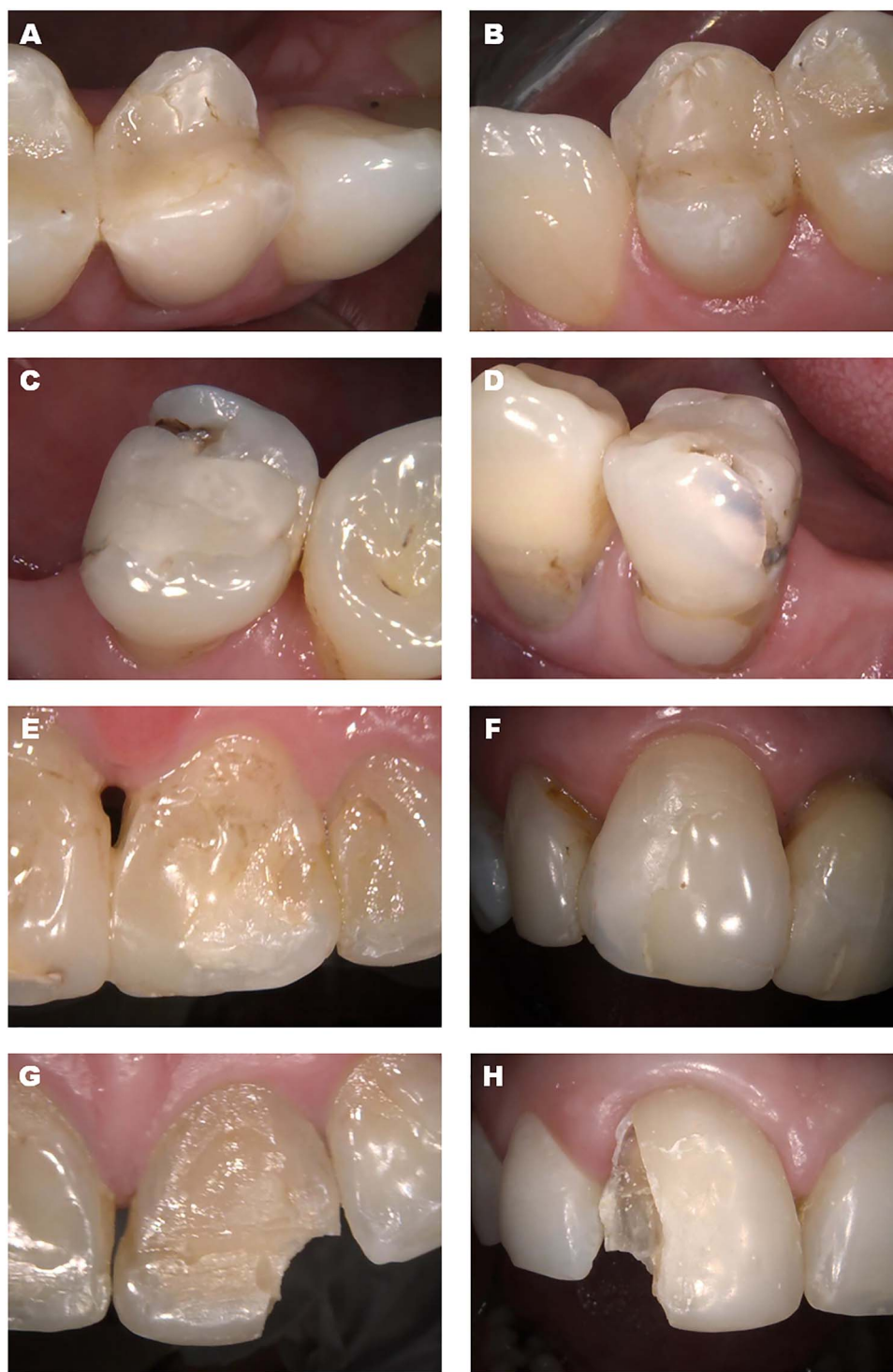


Fig. 1. Digital photographs of restorations. Each restoration is shown at two different angles (A/B, C/D, E/F and G/H). A/B: posterior restoration without failure; C/D: posterior restoration with failure; E/F: anterior restoration without failure; G/H: anterior restoration with failure.

(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.

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.

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 ^a	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 ^a	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 ^a	6 (8.6)	8.6–21.3	5 (7.1)	2.4–15.9	11 (15.7)	8.1–26.4

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

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 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.

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

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 ^a	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 ^a	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 ^a	0.29	86.4	0.43	84.3

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

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

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

		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).				

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.

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.

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.

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.

Conflict of interest

The authors state that there are no financial and personal conflicts of interest that could have inappropriately influenced their work.

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