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Enhancing Radiographic Precision: The Role of Digital Subtraction Radiography and Histogram Analysis in Radiographic Evaluation of Early Approximal Caries

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ABSTRACT

Evaluating initial approximal caries lesions through radiographs remains a cornerstone of clinical research, with a variety of methods available to address this challenge. Traditionally, bitewing radiographs have served as the primary tool for assessing changes in lesion depth, but as dental practices continue shifting toward prevention rather than intervention, the demand for reliable techniques capable of detecting early lesion size changes has grown.

This study builds upon the foundational work of the doctoral dissertation of the first author, which focused on the effectiveness of preventive measures on the progression of approximal caries lesions using radiographic follow-up methods. Expanding on that groundwork, this manuscript explores different approaches to radiographic-evaluation techniques, addressing critical gaps in the field.

Specifically, the paper explains three radiographic interpretation methods: 1. digital subtraction radiography (DSR), 2. histogram analysis (HA), and 3. a combination of the two. Our findings reinforce the value of DSR as a highly sensitive tool that complements visual interpretation, especially in high-risk caries cases. Yet, challenges in correctly performing and interpreting DSR radiographs persist. To address this, we provide practical guidance for performing and interpreting DSR and propose a novel method that integrates DSR with HA, enhancing diagnostic accuracy and offering a new perspective on radiographic evaluations.

Keywords: Initial approximal caries, Proximal caries, Bitewing radiographs, Digital subtraction radiography, Histogram analysis.

1. Introduction

Radiography plays an essential role in dentistry, working hand-in-hand with clinical examination to provide a comprehensive diagnostic picture (1). Radiographs help clinicians detect and diagnose carious lesions and other intra-oral diseases. Smooth surface caries lesions, especially those on proximal surfaces of teeth, can be difficult to detect clinically (2). Bitewing radiographs are a type of intra-oral radiograph used to detect approximal lesions, especially those that are still in the early stages of the disease process. International Caries Classification and Management System (ICCMS) introduced a radiographic scoring system to classify approximal lesions' progression on bitewing radiographs. This system is summarized in Table 1 (3).

Table 1: ICCMS radiographic scoring system

Stage	Score	Radiographic interpretation
No radiolucency	0	No radiolucency
RA: Initial stage	RA1	Radiolucency in the outer ½ of enamel
	RA2	Radiolucency in the inner ½ of enamel ±EDJ*
	RA3	Radiolucency limited to the outer 1/3 of dentin
RB: Moderate stage	RB4	Radiolucency reaching the middle 1/3 of dentin
RC: Extensive stage	RC5	Radiolucency reaching the inner 1/3 of dentin, clinically cavitated
	RC6	Radiolucency into the pulp, clinically cavitated

* EDJ: refers to the enamel-dentin junction.

Early detection of approximal caries lesions is of paramount importance. When identified at an early stage, these lesions can be managed with preventive care or minimally invasive treatments, rather than resorting to more traditional methods of drilling and filling. By taking a more conservative approach, we can postpone the time point at which a tooth enters the restorative cycle. This ultimately helps the tooth remain functional and healthy in the patient's mouth for a longer time.

Digital subtraction radiography (DSR) is a technique that allows for the comparison of two geometrically aligned radiographs by subtracting the pixel values on a greyscale using computer software (4). When comparing radiographs taken at different times, a carious lesion that hasn't changed will appear grey, while any changes (progression or regression) will show as darker or lighter areas on the greyscale (4).

Several clinical trials have utilized DSR to monitor the progression of approximal caries lesions. For instance, Martignon et al. (2006) evaluated the effectiveness of resin infiltration *versus* standard oral hygiene instructions in arresting early approximal carious lesions using both DSR and visual assessment (4). They found that DSR detected twice as much lesion progression compared to visual assessment, concluding that DSR was the most sensitive and reproducible method for detecting carious lesion progression. Similarly, Paris et al. (2010) used DSR to assess the efficacy of resin infiltration in arresting approximal carious lesions, reporting high kappa statistics for DSR and nearly double the detection rate of lesion progression compared to visual assessment (5).

In endodontics, DSR can be used to study procedural errors, such as transportation and excessive widening of root canals. Zanesco et al. (2017) investigated apical transportation, centering ratio, and volume increase after cleaning and shaping root canals using hand instrumentation, rotary instruments, and reciprocating instruments. They found that DSR was as effective as micro-CT in imaging apical transportation (6).

In oral medicine, digital subtraction sialography is used to analyze obstructions in salivary glands. This involves injecting contrast media and taking multiple images, which can then be carefully analyzed to detect the cause and location of obstructions. Lee et al. (2015) concluded that digital subtraction sialography could detect all types of obstructions (7).

While all these studies used DSR for follow-up in different areas of dentistry, none of these studies clarified the way in which DSR was obtained. Furthermore, none of these studies explained how DSR was interpreted, making it equally difficult for clinicians and researchers to reproduce what has been done.

Histogram analysis can be used to obtain average greyscale score values providing an objective method to evaluate changes in DSR images (8). The combination of DSR and HA is a novel method that will help detect the change in approximal caries lesions through establishing parameters of magnitude change needed to perceive the change visually on radiographs.

Follow-up of approximal caries lesions' progression can be done through two main methods: pairwise visual comparisons and digital subtraction radiography (DSR). Literature on DSR is inconclusive and doesn't provide researchers with clear explanations on its use in clinical research. This paper aims to explain DSR and how to properly interpret the results in clinical research. This paper also introduces a novel method that combines DSR with Histogram Analysis (HA) for objective evaluation of approximal caries lesions.

2. Description of Technique

2.1 Digital Subtraction Radiography

To attain a subtraction radiograph, two bitewing radiographs of the same tooth surface were taken at different time points (baseline and follow-up). To ensure reproducibility, a bite registration holder was fabricated during the baseline visit. This holder was made using a stable bite-registration material (additional silicone) to accurately capture the patient's bite. The same holder was used during follow-up visits to ensure consistent positioning for the follow-up radiograph. All radiographs were taken using the same radiographic machine, with identical exposure settings, to maintain consistency. The images were stored in MiPACS (MiPACS Dental Enterprise Solution, Charlotte, NC, USA) and accessed via AxiUm platform (XTS Software, Portland, Oregon, USA).

To produce the DSR radiographs, two radiographs taken at two different time points were processed using Image Registration and Mosaicking software (Regeemy, DPI-INPE Sao Jose dos Campos, Brazil). This software uses "tie-points" to overlap the two radiographs and subtract the greyscale pixel values of the two images to highlight changes over time, generating the DSR image. Tie points are anatomical landmarks (cusp tip, DEJ, CEJ, ... etc.) or clear points on the radiograph such as a restoration margin. The selection of tie points can be automatic and can be manually adjusted as needed. Figure 1 presents an example on tie-point selection using Regeemy software.

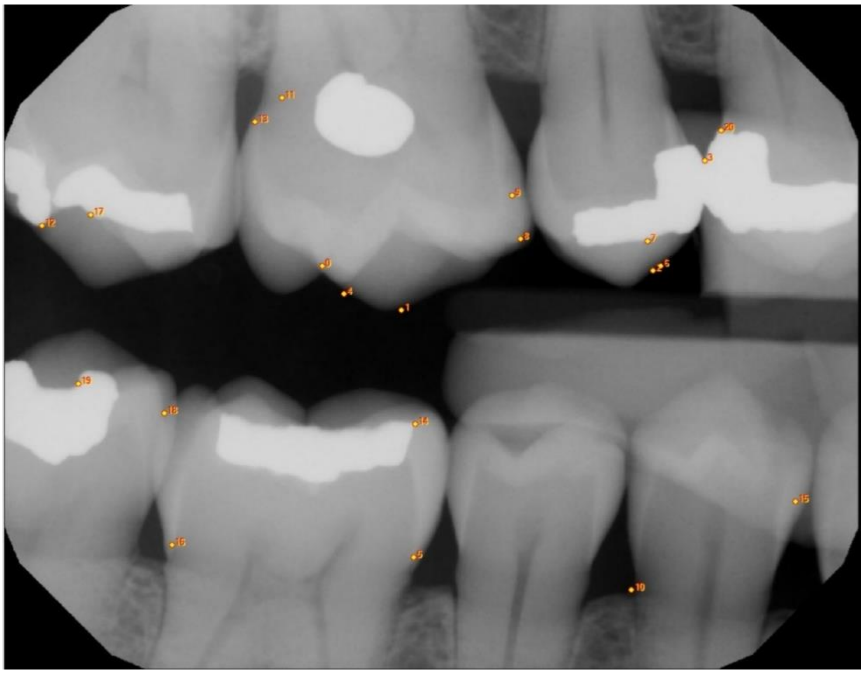

Figure 1: Tie-point selection in Regeemy software. Note the bite registration holder with bite registration material that was used to take the bitewing radiograph, and the window cut made to see the approximal lesion on the mesial surface of the upper right first molar

To analyze the change in lesions, the resultant DSR image was analyzed using ImageJ software (NIH, Bethesda, MD, USA). A specific area at the center of the lesion was examined to determine the greyscale score, which reflects the changes in the lesion. All evaluations were performed visually on a high-quality medical-grade display (Barco 3MP, Kortrijk, Belgium) in a dimly lit room, ensuring optimal conditions for accurate interpretation.

2.2 Histogram Analysis

For the purpose of objective evaluation of subtraction radiographs, we used histogram analysis to obtain average greyscale score values of the DSR radiographs. We used ImageJ software to analyze a 25*25-pixel area located on the center of the lesion. Greyscale scores range from 0 to 255. The closer the values to the median value (~127.5), the more supportive the data for "no radiographic change". Values smaller than the median (positive change) were suggestive of increased density and hence, "radiographic regression". On the other hand, values higher than the median are suggestive of decreased density (negative change) and hence, "radiographic progression" (11).

It's estimated that a 30%-60% change in demineralization is needed before it can be detected on conventional radiographs (9). Currently, no studies defined the magnitude of changes in greyscale values needed to detect progression or regression. In Jaradat et al. (2021) (8), no significant differences were observed in overall greyscale scores between two study groups (SDF *vs*. control) at baseline, 6, and 12 months. The average greyscale score for the SDF group ranged from 127 to 130, while that of the control group ranged from 125 to 128 (p= 0.395-0.921). This study was the first to establish magnitude change parameters for DSR detection. We found that a change of 2-3 from the median was necessary before a change in lesion size could be detected visually (8).

2.3 Combining DSR and Histogram Analysis

We looked at summary statistics for DSR group combining all readings at all time points where no radiographic change, radiographic progression and radiographic regression were recorded. Then, we examined what ranges of histogram greyscale values were associated with which values of DSR. For example, for all study readings at all time points, 66 readings were recorded as no radiographic change. After that, we looked at the individual greyscale score values for these readings and calculated the change from the median (equation: 127.5-greyscale score). This was calculated for all the three events at all time points. Results are reported in Table 2 as mean (average of 127.5-greyscale score), standard deviation, minimum, maximum, and median.

Table 2: Summary statistics of histogram greyscale score changes by DSR

DSR	N	Mean	SD	Min.	Max.	Median
No radiographic change	66	-0.59	8.53	-38.69	14.07	0.33
Radiographic progression	11	-2.94	7.53	-21.58	7.73	-1.27
Radiographic regression	15	3.32	2.99	-1.52	9.53	2.87

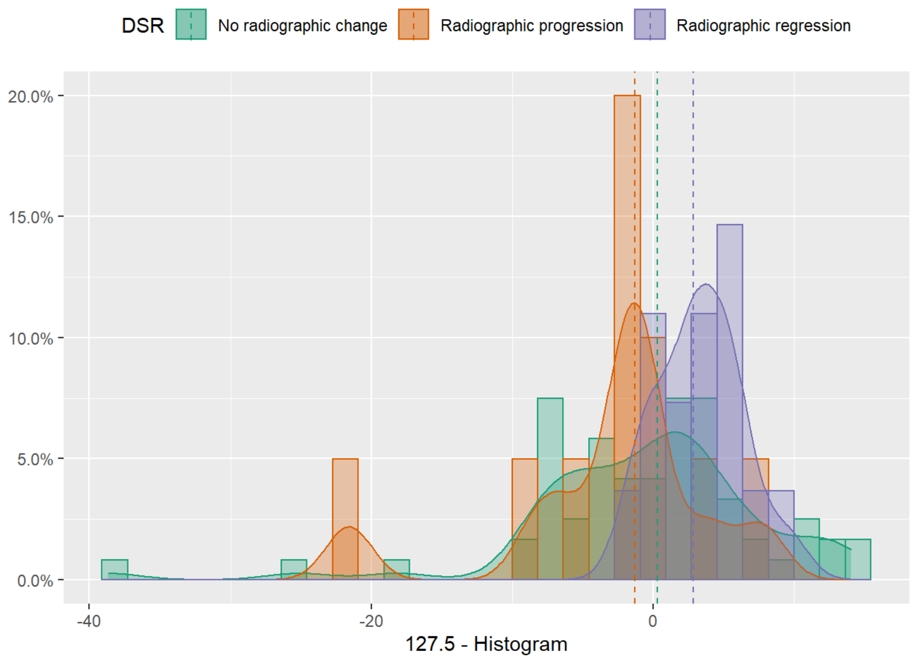

Figure 2: Combining DSR and histogram analysis (HA) ranges

No radiographic change had a mean histogram difference of -0.6, and a median of 0.33, and thus, was relatively centered around 0. Radiographic progression was centered around approximately -2, while radiographic regression was centered around positive 3. This was expected, since readings more than 127.5 (negative values) corresponded to progression, while readings less than 127.5 (positive values) corresponded to regression. Figure 2 plots these values by DSR categorization. The vertical lines in this plot represent the medians of each group. On the x-axis, we have the difference between the mean histogram and 127.5. The height of each bar at different histogram values corresponds to how often the combination of that histogram value and the colored DSR value occurred. The shaded areas show the overall pattern of histogram values for each DSR group.

3. Discussion

A subtraction radiograph can be obtained in two ways. One method involves subtracting the baseline radiograph from the follow-up radiograph (image2 - image1). Alternatively, DSR can be performed by subtracting the follow-up radiograph from the baseline radiograph (image1 - image2). Both methods were used in dental literature (2,6,7,9-11).

It is important to understand and acknowledge the method used in subtraction, because it affects greyscale values and the interpretation of DSR images. If the first method (image2 - image1) is used, an increase in greyscale value or a lighter area on the DSR image indicates radiographic progression (11). Conversely, a decrease in greyscale value or a darker area suggests radiographic regression or remineralization (11). The opposite is true if the second method (image1 - image2) is used (5). Figure 3 illustrates changes in density in DSR images on a larger scale, subtracting the baseline image from the follow-up image (image2 - image1). The patient had root-canal treatment for the upper right first molar and a subsequent onlay restoration on the same tooth. The darker shade of the root-canal space and the occlusal surface of the upper right first molar reflects the increased density after being filled with gutta-percha and receiving a metallic onlay. The neutral grey shade on most of the resultant DSR radiograph represents no change in density.

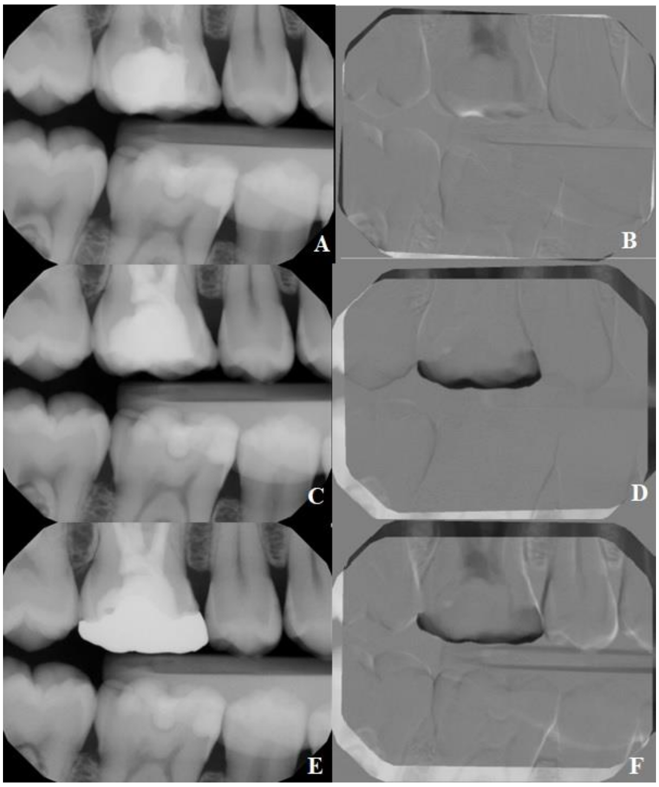

Figure 3: Explanation of radiographic-density changes as seen in DSR (image2-image1).
A. Baseline radiograph. B. DSR radiograph of baseline and 6 months after receiving the RCT for the upper right first molar (darker root-canal space). C. Radiograph 6 months after receiving RCT for the upper right first molar. D. DSR radiograph of 6 and 12 months after cementation of a metal onlay on the upper right first molar (darker occlusal surface). E. 12 months after the onlay cementation. F. DSR radiograph of baseline and 12 months after receiving the RCT and onlay for the upper right first molar (darker root-canal space and occlusal surface)

Another crucial factor to consider is the quality of the resultant subtraction radiograph. Higher-quality radiographs enhance the examiner's ability to accurately perceive changes, distinguishing between "change" and "no change." Conversely, lower-quality radiographs can lead to misinterpretations, where shades in the resultant image might be mistakenly seen as progression or regression. Figure 4 illustrates this with examples of two subtraction radiographs of different quality, compared to a control DSR radiograph. When assessing the progression of initial approximal caries lesions (RA1, RA2, RA3), any variation in vertical angulation can be erroneously interpreted as progression or regression.

Figure 4: Explanation of DSR quality. A. High-quality DSR (lower right first molar-mesial): Homogenous neutral grey color in the area of interest represents "no change". B. Control DSR: Perfect DSR produced by subtraction of the same radiograph. Note the prefect homogenous neutral grey color. C. Lower-quality DSR (lower left second premolar-mesial): Lower-quality DSR showing the effect of slight vertical angulation change resulting in shadowing in the area of interest. The whitish shadow (lower left second premolar-mesial) could be mistakenly interpreted as progression.

4. Conclusions

In conclusion, DSR is a versatile and effective method used in various fields of dentistry. Evidence indicates that DSR is a reliable technique for assessing changes on both small and large scales. It's important to understand and acknowledge the specific method used for DSR, as well as its limitations, particularly regarding the quality of the radiographs obtained. This understanding is crucial for relying on DSR as a method of evaluation.

When combining DSR with HA, we can objectively evaluate changes in caries lesions through assessing the magnitude of change. This novel method is effective and reliable, especially when evaluating small changes in lesion size. This can help clinicians make better decisions regarding the management of caries lesions, especially in populations of higher risk. Future research can utilize Artificial Intelligence (AI) to make the process easier for clinicians. Artificial Intelligence can be utilized through machine learning to perform subtraction, eliminating the need for precise positioning of radiographs. This will eliminate the technical difficulties encountered. AI can also quantify the change in greyscale values, thus providing clinicians with an objective insight into lesion progression.

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