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ORIGINAL ARTICLE

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The monitoring of deep caries lesions after incomplete dentine caries removal: results after 14–18 months

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Abstract This paper aims to assess radiographic changes after incomplete carious dentine removal and tooth sealing. Thirty-two teeth with deep caries lesions were studied. The treatment consisted of incomplete excavation, application of a $Ca(OH)_2$ layer, sealing temporarily for a 6- to 7-month period and then restoration. Standardised bitewing radiographs were taken immediately after the temporary sealing and at 6- to 7- and 14- to 18-month intervals. The digitised images were analysed blind by image subtraction. The quantitative analyses subtractions were performed in the radiolucent zone (RZ) beneath the restoration and in two adjacent control areas (CA). Two cases were lost during the 6- to 7-month period (one pulp necrosis and one pulp exposure during removal of the provisional sealing). No difference (p>0.05) was observed in the radiographic density of the CA and the RZ in the two experimental periods. The mean and standard deviation (grey tonalities scale) were 129.42±5.83 and 127.65±4.67 (control areas) and 132.96±7.41 and 132.90±5.99 (RZ) for the first and second experimental periods, respectively. The radiographic density of the CA differed from the RZ (Tukey test, p<0.001). Interference in environmental conditions by partial dentine caries removal and tooth sealing arrests lesion progression, suggesting that complete dentine caries removal is not essential to control caries progression.

Keywords Carious dentine removal · Deep caries lesion · Remineralisation

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Introduction

A decrease in cariogenic biofilm activity may affect dental mineral loss causing inactivation of tooth decay. This occurs with and without the presence of a cavity in dentine. A smooth and shiny surface is characteristic of a non-cavitated inactive lesion and is caused by a change in local environment conditions, while changes in colour and consistency of dentine have also been cited as an indication of arrest of cavitated lesions [2, 6, 30]. Sometimes, at advanced stages of caries, the resulting cavity impairs biofilm control. At this stage, operative dentistry is usually recommended. The infected demineralised dentine is completely removed before the placement of the restoration. However, there is little evidence that the infected dentine must be removed before sealing the tooth [26, 27].

The sealing of dental cavities for periods of 6 to 19 months, i.e. isolation of the decayed area from the mouth, causes a reduction in microorganisms with no evidence of an increase in size of the lesion [5, 6]. No progression of dental caries has also been observed in cavities sealed for a period of 10 years [33].

The halting of the progress of tooth decay by interfering with the metabolic activity of microorganisms can be observed in cases of deep carious lesions [6]. This has been seen in various studies using indirect pulp capping therapy or stepwise excavation [1, 6, 15, 30]. This latter treatment consists of the incomplete removal of softened dentine during cavity preparation and leaving a layer of soft dentine over the pulp so that it is not mechanically exposed. The partial removal of carious dentine on the pulp wall and the sealing of the cavity at varying intervals are recommended [26] to arrest lesion progression and to reduce the permeability of the dentine by sclerosis and tertiary dentine formation [8, 32]. After a period has elapsed, it is suggested that it is necessary to reopen the cavity and remove the remaining decayed dentine. This two-part clinical procedure aims to avoid exposure of the pulp [29].

Studies show that, during the treatment interval, there is substantial bacterial reduction and the remaining carious dentine exhibits the characteristics of inactive lesion. The dentine left is mostly hardened [6, 30], and no signs of caries progression were found [5, 30]. In spite of this, however, the profession still claims that all soft dentine should be removed before restoration [7, 22, 23]. It is not clear whether it is a necessity to re-enter restorations to remove the remaining soft dentine; indeed, this procedure may compromise the treatment. The removal of residual carious dentine, after the interval of treatment, might result in an unnecessary risk of pulp exposure [29]. The exposed pulp can be severely damaged during the restoration procedures [35], thereby affecting defence mechanisms. The possibility of carrying out partial caries removal and restoring the cavity in a single session might provide more favourable conditions for the healing of the pulp. This clinical practice would eliminate the inconvenience of the two-step treatment. Results after 6–7 months proved the efficiency of this approach [30]. However, it is not clear if residual bacteria beneath restorations represent any danger for the longevity of restorations. Long-term clinical research is necessary to evaluate whether the two-step treatment is required.

The aim of the present study was to evaluate the long-term effect of incomplete removal of carious dentine and restoration of teeth for a period of 14–18 months. The mineral content of the remaining carious dentine was also evaluated.

Materials and methods

The study was approved by the Ethics Committee of UFRGS (Federal University of Rio Grande do Sul) and all patients signed an informed consent.

Sample and inclusion criteria

The sample consisted of 32 permanent posterior teeth from 27 patients (12–23 years of age) with deep carious lesions: 17 teeth had only an occlusal lesion, three had only an approximal lesion and 12 had an approximal, buccolingual or palatolingual lesion as well as an occlusal lesion. Only the teeth judged radiographically to be at risk of pulp exposure if the demineralised dentine was completely removed were included. None of the teeth had spontaneous pain or sensitivity to percussion. Absence of periapical lesion was observed through radiographic examination. Pulp sensitivity was verified by a cold test with −20°C refrigerated gas (Aerojet, Rio de Janeiro, Brazil).

Experiment design

The treatment consisted of incomplete carious dentine removal and clinical and radiographic monitoring for a period of 14–18 months.

Restoration procedure

After anaesthetic and rubber dam isolation of the area to be treated, the following procedures were carried out: (1) access to the affected area using a #245 carbide bur if necessary, (2) removal of the superficial part of the necrotic and fragmented dentine with an excavator leaving a layer of soft dentine on the pulp wall to avoid pulp exposure, (3) carious tissue was then completely removed from the walls surrounding the cavity using sterilised round steel burs at low revolutions per minute (tissue was removed until the area was clinically hard), (4) washing of the cavity with saline and drying with sterile swabs, (5) protection of the pulp wall with calcium hydroxide cement (Dycal, Caulk/Dentisply, Rio de Janeiro-Brazil) and (6) sealing of the cavity with modified zinc oxide-eugenol cement (IRM, Caulk/Dentisply, Rio de Janeiro, Brazil). After an interval of 6–7 months, the clinical symptoms and pulp sensitivity were evaluated by means of the cold test (Aerojet, Rio de Janeiro, Brazil). The temporary filling was removed. The dentine was clinically and microbiologically assessed (data already published) [30]. No carious dentine removal was undertaken. Calcium hydroxide cement was applied (Dycal, Caulk/Dentisply, Rio de Janeiro, Brazil). The teeth were then restored with a light-cured resin composite resin (Charisma, Kulzer, São Paulo, Brazil) using the Scotchbond Multi-Purpose (3 M, St. Paul, MN, USA) bonding system.

Radiographic examination

The radiographic examinations were carried out in the following manner: (1) periapical radiographs was used as a diagnostic aid; (2) after the incomplete removal of the demineralised dentine and the temporary filling of cavity, a bitewing radiograph was taken to allow analysis of the radiolucent zone (RZ), that is, the amount of demineralised dentine left; (3) after 6–7 and 14–18 months, periapical and bitewing radiographs were taken to analyse the integrity of the periapical area and the eventual changes in the RZ.

Radiographic technique standardization

To obtain geometric standardization of films, bitewing film holders were used. A piece of self-cured acrylic resin was placed on the film holder (Jon, São Paulo, Brazil) which was then placed on the occlusal surface of the experimental tooth and its antagonist to form an impression of the anatomy of this surface. It was, therefore, possible to relocate the device in the same position in the different experimental periods. The device has a shaft that was placed in a groove located on the X-ray cylinder, enabling all the radiographs to be standardised so that the central X-ray was in the same both vertical and horizontal directions. A short rod, fixed to the device, standardised the film-focus distance. Ektaspeed Plus no. 2 film (Eastman Kodak, NY, USA) and 50 kV, 10 mA and Spectro II equipment were used. Exposure time was 0.6 s. Development and fixation procedures were carried out using a 9000 model automatic processor (DENT-X, NY, USA).

Radiograph analysis

The images obtained before and after the treatment were digitised by a ScanJet 6100 scanner Hewllet-Packard (OR, USA). The images were stored in maximum quality JPG format. The Imagelab software (version 2.3, Softium-Sistemas de Informatica, São Paulo, Brazil) was used to analyse the images (equalise and subtract).

Change in the density measurement of the RZ during treatment was evaluated blind through digital subtraction of radiographic images in relation to the initial exams in the two experimental periods (6–7 and 14–18 months). The radiographic subtraction process consisted of comparing two images. By definition, a digital subtraction image from a site where no change in density had occurred would show a complete cancellation of all anatomical structures, eliminating the constant structures present in both. Any change in the structures indicates a change in density. This method required standardised radiographs regarding the X-ray projection, exposure time, film and development. Nonetheless, the procedures were standardised; radiographs were performed at different moments, which cause them to have different density [16, 39]. To correct for any changes in density, the grey level histograms of the two images were compared and adjusted using a non-parametric contrast correction algorithm [39]. The image radiograph equalisation was done in the following way: the radiograph taken immediately after the treatment and the one taken after each period of treatment (6–7 or 14–18 months) were placed beside one another on the computer screen. The radiograph that showed the best distribution of grey tonalities on the histogram was chosen as a model, and the other image was equalised according to the model.

The subtraction was carried out the following way: the radiograph taken immediately after the treatment and the images obtained after each of the experimental periods were overlapped. The anatomic details of the two images were matched by rotation or moving the images horizontally or vertically. The radiolucent zone beneath the restoration and two control areas (CA_1 and CA_2) were selected. The control areas were dentinal areas (mesial and distal) close to the RZ. The difference in radiographic density between the two radiographs was determined for each selected area using a grey tonalities scale. There are 256 individual shades of grey in an 8-bit pixel going from 0 (black) to 255 (white). This is the pixel's grey scale resolution [24]. An average grey level value of 128 (the middle of the digitiser grey level range set by software) would show up at each pixel. Areas with grey levels <128 in the subtraction image would indicate loss in density and grey levels >128 would indicate increase in density [9, 11].

Reproducibility

A single operator carried out all evaluations. The subtractions were carried out five times for each tooth. The value for each area (CA_1, CA_2 and RZ) was the mean of the five measurements. All the measurements were repeated after an interval of 5 days.

Statistical analysis

The reproducibility of these repeated subtraction means was analysed using the paired Student *t* test. The means of the control areas and RZ were compared by multiple variance analysis, using the outlines of random blocks together with Tukey's multiple comparison test at a significance level of 5%.

Results

In the 6- to 7-month interval, 31 out of the 32 cases did not present any clinical symptoms (sensitivity to cold, hot,

Table 1 Means and standard deviation (SD) of the repeated digital subtraction (first and second exams) of radiographic images from the 6- to 7- and 14- to 18-month examinations

Repetitions		6–7 months			14–18 months		
		Mean	SD	*p*	Mean	SD	*p*
First exam	CA_1	129.09	5.84	0.61	126.76	4.99	0.45
Second exam	CA_1	128.66	5.84		126.33	4.94	
First exam	CA_2	129.76	6.88	0.64	128.53	5.77	0.13
Second exam	CA_2	130.14	7.47		127.40	6.53	
First exam	RZ	132.97	7.43	0.36	132.90	6.01	0.27
Second exam	RZ	132.01	6.02		131.78	6.40	

Data from the control areas (CA_1 and CA_2) and radiolucent zone are shown sweet or pressure, or spontaneous pain) and gave a positive result to the cold test. The study results of this period concerned 30 cases due to loss of two cases. One tooth presented pulp necrosis and, in another case, there was a pulpal exposure during the removal of provisional sealing. During the 14- to 18-month interval, it was not possible to contact seven patients and one patient left the trial. During this period, radiographic monitoring was, therefore, carried out in 22 cases. None of the cases presented any clinical symptoms during the trial period and all gave a positive result to the cold test. There were no case failures between 6–7 and 14–18 months.

A small variation was observed in the five repetitions of the subtraction measure (standard deviation of <7.5 shades of grey). The reproducibility of the repeated subtraction means shows no difference between the examinations carried out with a 5-day interval (Table 1).

The subtraction (grey levels) of the control areas, throughout the study, shows values close to 128 indicating no mineral changes. The subtraction of the RZ showed grey levels higher than 128 suggesting mineral gain. The subtraction values of the control areas differed from those of the RZ ($p<0.001$). No difference ($p>0.05$) was observed in the radiographic density of the control areas between the two experimental periods; the same situation was observed for the RZ. These results suggest that the mineral change took place in the 6- to 7-month interval (Fig. 1).

Discussion

Incomplete carious dentine removal and the sealing of the cavity produce an increase in radiographic density indicating mineral gain and apparent arrest of the carious process.

The evaluation of the stepwise excavation is usually carried out by sensitivity tests (cold test) that may indicate pulp vitality and periapical radiographic examination to

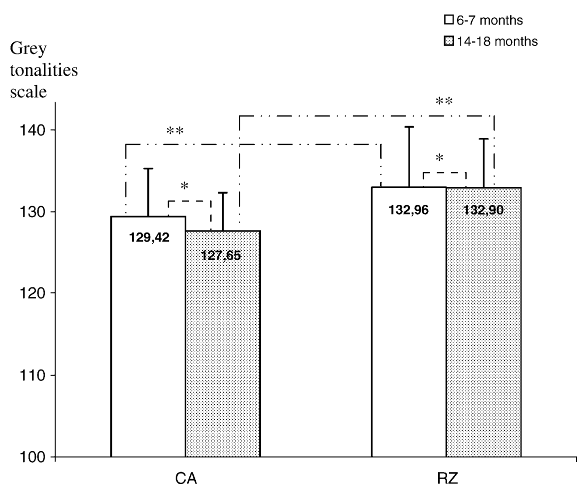

Fig. 1 Mean and standard deviation of radiographic subtraction density of the control areas (*CA*) and radiolucent zones (*RZ*) in relation to the initial exams in the two experimental periods (6–7 and 14–18 months). *$p>0.05$; **$p<0.05$

observe the state of the periapical tissues. In this study, we have also used a bitewing examination to study the behaviour of the demineralised dentine by radiographic image subtraction (quantitative analysis).

Longitudinal clinical studies require patient collaboration, not only by attending follow-up appointments but also by informing the researchers of any change of address or employment and any planned trips. These factors frequently impair contact with the patient, interfering with the monitoring interval and the maintenance of the initial sample size. These problems occurred in this study. Of the 27 patients examined after 6–7 months of treatment, seven could not be reached 14–18 months later and one left the experiment.

The reliability of digital radiographic image subtraction depends on the standardising of all the variables involved in the image acquisition [14, 43]. The most critical factor is the reproduction of a constant position between the source of the X-ray and the patient. To standardise this, an acrylic resin mould of the bite mark of the tooth in question together with neighbouring teeth was adapted to a commercially available film holder. The device has a shaft that enables the operator to place the central ray in the same direction both horizontally and vertically. Others have used a cephalostat to standardise X-rays [14, 21]. Small differences in the tooth position between examinations were controlled during the image subtraction procedures available in the software. Uncontrollable differences concerning image processing were corrected by equalising the images after digitalisation using a histogram of the distribution of grey tones [39] that allowed the differences of density that were observed to be attributed to the alteration of mineral content in the area under analysis.

The reproducibility among different examiners in the radiographic monitoring of tooth decay is problematic when using the conventional method and the qualitative subtraction method [45]. The quantitative subtraction method attempts to eliminate subjectivity when interpreting the radiograph once the area to be analysed has been quantified, thereby permitting numeric comparison. The evaluation of concordance among examiners was not the objective of this study as only one individual analysed all the images. The study was conducted blind in relation to the periods when the images were taken, the subtraction was repeated five times in sequence and, after a period of 5 days, the reproducibility of the obtained data was verified. Statistical analysis showed that there were no differences in these values, thereby showing the method to be reliable. This was also shown to be true using the standard deviation method [12]. The desired outcome using stepwise excavation is to favour deposition of tertiary dentine and remineralisation of the remaining demineralised dentine. This occurrence is difficult to document over time using conventional radiographic techniques that cannot detect small mineral alterations [45]. The use of the quantitative subtraction method allows verification of any change that may have occurred in the area under observation in numerical terms.

One important step in the restoration process is the carious dentine removal. The restorative dentist claims that all carious dentine should be removed before a definitive restoration is placed [44]. Caries beneath restorations are believed to be the main reason for restorative failure [34]. In deep carious lesions, stepwise excavation has been advocated to avoid harm to the pulp tissue. Clinical procedures consist of removing partially the carious dentine and leaving a layer of dentine over the pulp so that it is not mechanically exposed [13]. The tooth is provisionally sealed and it is expected that tertiary or sclerotic dentin will form [32]. In this treatment, the teeth are reopened and the carious dentine is then totally removed. The aim of caries removal is to ensure the longevity of the restoration through the elimination of bacteria. However, there is evidence that this assertion is not necessarily true. It is accepted that root caries can be treated by biofilm control [36] even though it is known that this type of lesion harbours bacteria within the dental tissue. In this case, it is not advocated, after caries process has been halted, that the infected dentine should be removed and a filling be placed. The mechanism that causes the arrest of deep carious lesions does not appear to be different from that observed in non-cavitated surfaces during tooth eruption [4, 10], after mechanical removal of biofilm from non-cavitated [19] or cavitated lesions [2]. The common factor in all these cases is the disturbance of the biofilm, disturbing bacterial adherence, metabolism and reproduction with a consequent decrease in the production of the acid responsible for the demineralisation and toxicity to the pulp.

The present study suggests maintenance of pulp vitality over a period of between 14 and 18 months. Bjørndal et al. [6], studying stepwise excavation, only removed necrotic and superficially infected dentine and then sealed the cavity for a period of 6–12 months. This procedure resulted in a significant decrease in viable bacteria and changes in colour and hardness corresponding to those of arrested caries. On reopening the cavities, the carious dentine was totally removed even though there was evidence that the carious lesions were arrested. In this study, the methodology and the baseline results were similar to those of Bj∅rndal et al. [6]; however, the residual decayed dentine was left under the restoration [30]. This treatment is based on the idea that it is not necessary to reopen the cavity to remove the demineralised dentine as the sealed active demineralised dentine turns to inactive and harbours fewer bacteria [6, 30]. The mechanical procedures used in the reopening of the cavity and removal of remaining decayed dentine may injure the pulp, increase the risk of pulp exposure and submit the patient to an additional appointment.

The incomplete carious dentine removal in deep lesions is based on scientifically based biological evidence. Clinical criteria for the removal of decayed dentine, be it hardness or colouring, do not ensure the absence of bacteria [25, 30, 41] because bacteria are usually left after conventional caries dentine removal. The remaining bacteria do not promote lesion progression after the dentine has been isolated from the oral environment [5, 17, 33, 38]. Pulp inflammation eases during the process of lesion inactivation [28].

The subtraction radiographic images indicated zone remineralisation of residual sealed decalcified dentine after a period of 14–18 months. This was also observed in experiments using scanning electronic microscopy [20, 31] biochemical analysis [13] and radiography [22]. The remineralisation of decalcified dentine appears to be a consequence of lesion arrest [40]. Clinical analyses of the sealed demineralise dentine (data shown in a previous study) [30] showed colour and consistency characteristics of arrested lesions. Interference in microbial metabolism by removing the necrotic dentine and isolating bacteria from the oral environment reduces caries progression, thereby allowing the defensive reactions of the dentine–pulp complex. The continual production of acid in active lesions, on the other hand, may affect cellular responses that will adversely affect the deposition of tertiary dentine [8]. The mineral increase suggests a reaction of the pulp–dentine complex that may be sclerosis, a deposition of tertiary dentine or both. The deposition of tertiary dentine after indirect pulp capping has been histologically [18] and radiographically demonstrated in deciduous teeth [3]. The mineral increase observed in this study over a 6- to 7-month period did not show any change after an additional 7 to 12 months. This increment in limited mineral increase over this 6- to 7-month period suggests that the cessation of the stimulus caused by the drastic decrease in bacteria [30] allowed pulp repair, interrupting the need for a defence response. Sclerotic dentine is less permeable than primary dentine [37, 42], thereby preventing toxic agents from microbe metabolism or materials used for sealing cavities from reaching the pulp. This defence reaction controls the inflammation reaction to the caries process allowing the pulp to repair itself. This is proven by the absence of periapical lesion on the radiographic examination and the lack of pain in all cases evaluated during the 14- to 18-month period. Ten-year monitoring of teeth with fillings covering carious tissue that was limited to the external third of dentine concurred with the present results [33].

In the present study, we have seen the inactivation of the caries process after incomplete carious tissue removal and sealing through a clinical and radiographic evaluation over a period of between 14 and 18 months. The results show that bacteria inside cavities tissue are not harmful once they are isolated from the environment.

Conclusion

Interference in the environmental conditions by partial carious dentine removal and tooth sealing for a period of 14–18 months causes an increase of the radiographic opacity of the radiolucent zones, suggesting:

- Mineral gain in the 6- to 7-month period
- An arrest of lesion progression

Complete dentine caries removal does not seem to be essential to control caries progression.

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