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Clinical Research

Temporary Tooth Separation to Improve Assessment of Approximal Caries Lesions: A School-Based Study

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Clinical Relevance

Radiographic lesion depth should not be used as the single determinant of the restorative threshold for clinically inaccessible approximal caries lesions. Temporary tooth separation is a feasible and effective diagnostic aid for assessment and appropriate management of approximal lesions.

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SUMMARY

In the era of tooth-preserving dentistry, the decision to restore approximal caries lesions must be based on the accurate assessment of

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tooth cavitation, as the accumulation of oral biofilms in these areas encourages lesion progression. However, lesions radiographically into dentin remain the main threshold criterion for restoring approximal lesions even though most of these lesions may not be cavitated. A school-based clinical protocol for temporary tooth separation (TTS) was developed to improve visual-tactile assessment and management of clinically inaccessible approximal lesions. TTS data retrieved from electronic health records were used to correlate radiographic lesion depth and surface cavitation status with lesion location and the patient's caries risk and to evaluate the effectiveness of TTS as a diagnostic aid for approximal lesions. Of the 206 lesions assessed, 66.5% (n=137) were located in the maxillary arch, 56.6% (n=116) in distal surfaces, 61.3% (n=114) in premolars, and 21.5% (n=40) in molars. After tooth separation, 79.6% (n=164) of the lesions were diagnosed as noncavitated, including 90% (n=66) of the lesions radiographically at the inner half of enamel (E2) and 66% (n=49) of those at the outer-third of dentin (D1). Logistic regression analysis using E2 and D1 lesions showed no significant association between lesion depth or cavitation status with lesion location and caries risk. TTS is a feasible and effective diagnostic aid for the assessment and appropriate management of approximal caries lesions. There is a need to reevaluate the use of radiographic lesion depth as the single determinant of the restorative threshold for clinically inaccessible approximal lesions.

INTRODUCTION

Substantial knowledge of the caries process based on over 100 years of caries research supports the use of preventive, risk-based, and tooth-preserving approaches for caries management.[1] Caries is well known as a biofilm-mediated disease.[2] That is, tooth cavitation or any situation in the oral environment that encourages the accumulation and metabolic activity of oral biofilms (dental plaque) increases the risk for caries development and progression. Efforts to arrest caries activity using biofilm control and remineralization therapy must take place at all times but especially prior to enamel cavitation.[3-5] Remineralization therapy aims to stop or reverse the progression of caries lesions by combining the use of fluoride products, education, and behavioral changes that promote mineralization over demineralization of dental tissues.[2] In contrast to the outdated and traditional surgical-only approach, the current consensus is that enamel and noncavitated carious lesions that can be arrested and remineralized by nonsurgical approaches should not be restored, whereas noncleansable and cavitated lesions progressing into dentin most often require restorative intervention.[6,7] In particular, the appropriate time to restore approximal lesions is when the lesions are cavitated because they are not cleansable or amenable to the effects of fluoride, and therefore these lesions are more likely to progress.

The decision to restore approximal caries lesions must be based on the accurate assessment of the presence of tooth cavitation. However, visual-tactile assessment of cavitation of these surfaces can be challenging due to the restricted access to contacting surfaces. Consequently, bitewing radiography has remained the primary detection method for clinically inaccessible approximal lesions. Since the probability of cavitation increases with lesion depth, lesion progression into the outer half of dentin, or D1 lesions, has become the threshold criterion for surgical (restorative) intervention of approximal lesions.[1,2] While bitewing radiographs are useful for detecting tooth demineralization, they may not reveal the surface integrity with accuracy.[8-10] In fact, earlier clinical studies revealed that between 40% and 60% of D1 lesions are not cavitated.[8,9,11-13] These findings imply that restorations leading to irreversible loss of tooth structure are commonly placed in teeth with noncavitated approximal lesions based on an age-old assumption that all caries lesions will progress if left untreated and not on accurate assessment of surface cavitation. Of greater concern, dentists' restorative thresholds remain unaffected by scientific evidence supporting less invasive management of noncavitated caries lesions. A systematic review shows that 21% of dentists or dental therapists would intervene restoratively on approximal lesions radiographically confined to enamel and that 48% would intervene restoratively on approximal lesions extending up to the dentin-enamel junction.[6]

The use of elastic orthodontic separators has long been proposed to achieve interproximal tooth separation and improve visual-tactile assessment of approximal tooth surfaces.[1,8-10,14] Unfortunately, this technique remains as an elective procedure that is not commonly used in clinical practice. Tooth separation allows the clinical evaluation of surface integrity (absence or presence of a microcavity or a distinct cavity) and lesion activity. A school-based

clinical protocol on temporary tooth separation (TTS) was developed to aid in direct visual-tactile assessment, thus facilitating accurate diagnosis and appropriate management of approximal caries lesions with an emphasis on preventive and minimally invasive restorative treatment planning based on the status of individual tooth surfaces. This study used electronic health records (EHR) of the TTS data to examine: a) the correlations between radiographic lesion depth, surface cavitation status, lesion location, and patients' caries risk, and b) the potential value of TTS as a diagnostic aid for approximal caries lesions.

METHODS AND MATERIALS

Study Design

This retrospective study used axiUm (Software Advice, Inc) electronic reports generated from patients' EHR to collect data on different variables related to the procedure of TTS, including radiographic lesion depth (outer [E1] or inner [E2] half of enamel, and outer [D1], middle [D2], or inner [D3] third of dentin), surface cavitation status (cavitated or noncavitated), lesion location (mesial/distal, maxillary/mandibular arch, and tooth type), and patients' caries risk level (extreme, high, moderate, or low). Data were collected for the period from August 29, 2017, to July 30, 2019.

Clinical Procedures

The procedures of clinical examination, radiographic interpretation, caries risk assessment, TTS, and development of treatment plans were performed by third- and fourth-year predoctoral dental students under the supervision of the attending clinical faculty from the Department of Restorative Dental Sciences. Students received didactic and preclinical training on diagnosis, prevention, and management of dental caries during their first two years of the DMD program. Faculty meetings and calibration sessions were conducted to discuss the scientific evidence available regarding caries diagnosis and management, which included the development and implementation of the TTS protocol. The school's caries risk assessment and management program was developed based on the Caries Management by Risk Assessment (CAMBRA) system as described elsewhere.[15]

Protocol for TTS

The indications and steps of the clinical and electronic-based protocol for TTS are shown in Figure 1. According to the protocol, TTS must be performed for the assessment of all approximal caries lesions showing no evident cavitation on visual-tactile examination and extending to the outer third of dentin (D1 lesions) upon radiographic examination. However, TTS is also recommended for other types of radiographic lesion depth when the lesion activity and/or surface cavitation are questionable. For the lesions assessed during the study period, the orthodontic bands were placed in the interproximal spaces, and TTS was performed for at least one hour but no longer than three hours. The protocol recommends the placement of bands as early in the dental appointment as possible to allow more time for tooth separation and thus achieve adequate visual-tactile assessment of the tooth surfaces. Of note, multiple lesions could have been assessed on the same patient during one or several dental appointments.

The TTS electronic-based protocol was developed and built into axiUm. The protocol consists of using an axiUm procedure code (D0426) and a form (DEPCAV) that are entered in each patient's EHR for each tooth surface assessed with tooth separation. The D0426 code was used to record the separation procedure and the tooth number and surface. The DEPCAV form was populated, linked to D0426, and used to provide further diagnostic information on radiographic depth and cavitation status (as determined clinically after tooth separation) of the caries lesions. Another protocol was developed to monitor active approximal caries lesions that had been assessed as noncavitated after tooth separation. The D0604 code was used to record the monitoring procedure and tooth number and surface, while the CMPLAN form (linked to D0604) was used to provide information on the patient's caries risk, radiographic lesion depth, time frame for recall visits, and the procedures to be performed at recalls (Supplemental Material 1).

Diagnosis and Management of Caries Lesions

After tooth separation, the approximal caries lesions were directly assessed and diagnosed by visual-tactile examination using the criteria shown on Table 1, which also shows the treatment recommendations according to the surface cavitation status (surface integrity) and activity of the caries lesions. Lesion activity was determined by clinical appearance and texture of tooth surfaces. Even though Table 1 shows that the color of tooth surfaces varied according to the type of dental tissue affected and lesion activity, color was not to be used as a

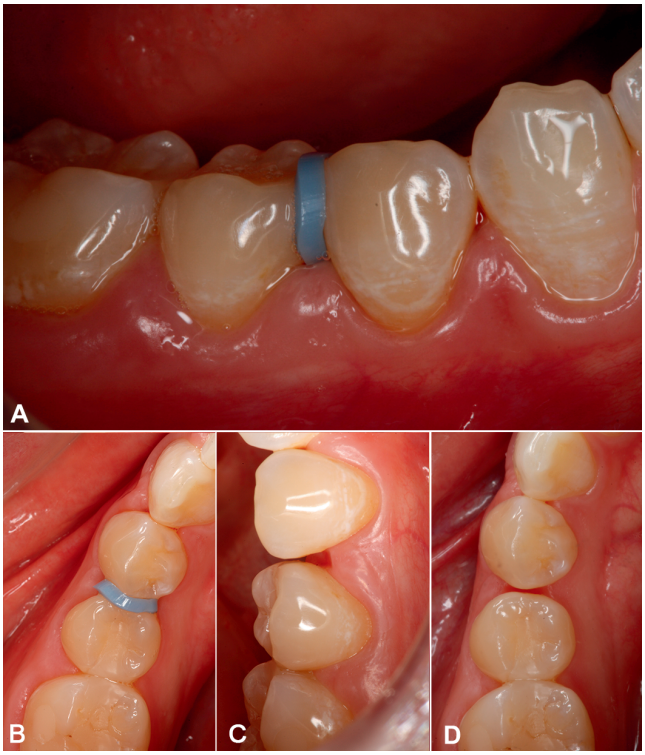

Figure 1. *Tooth separation and assessment of the mesial caries lesion of tooth 29; (a) and (b): Initial views of the orthodontic elastic separator between teeth 28 and 29 that remained in place for 90 minutes. (c) and (d): Clinical aspect after separation.*

Clinical and electronic-based protocol for temporary tooth separation.
Indication: Temporary tooth separation must be performed for the assessment of all approximal caries lesions showing no evident cavitation on visual-tactile examination and extending to the outer third of dentin (D1 lesions) on radiographic examination.
Clinical Steps:

1. *Inform the patient about the need, indications, advantages, and disadvantages of the tooth separation procedure.*
2. *Stretch the orthodontic bands outside of the mouth by using an orthodontic forceps or dental floss ligatures. There are two different sizes of orthodontic bands available in our clinics. Whenever possible, the tighter bands and perhaps two bands should be inserted into the interproximal spaces in order to achieve satisfactory tooth separation.*
3. *Work the orthodontic bands down through the contact point. The bands should be left interproximally for at least one hour, but longer separation time typically yields better results.*
4. *After the separation time, remove the bands gently by using cotton plyers, dental explorer, or dental floss.*
5. *Wash and dry the approximal tooth surfaces.*
6. *When the teeth are well separated, you should be able to visualize the tooth surfaces directly or indirectly (mirror) and, if needed, to "feel" the surface's texture by moving the tip of a dental explorer gently across the tooth surfaces.*
7. *Determine if caries lesions are present on the approximal surfaces. If the surfaces present no signs of past or present caries activity, this must be noted on the patient's progress notes, and no further treatment is necessary. If caries lesions are present, you must assess surface integrity (cavitated or noncavitated) and lesion activity (active or inactive).*
8. *For active and noncavitated carious lesions, fluoride varnish must be applied while the teeth are still separated. These lesions will be managed by nonsurgical procedures and monitored over time.*
9. *All clinical observations, caries diagnoses, and corresponding treatment plans must be identified and recorded in the patient's dental record.*

diagnostic characteristic to distinguish active from inactive lesions.

According to the protocol, and regardless of the patient caries risk, enamel and D1 lesions assessed as noncavitated active lesions were to be managed by nonsurgical procedures and monitored over time, while restorative treatment was to be planned for cavitated active lesions. At this point, the treatment of the noncavitated lesion was to be based on controlling patient's risk factors through therapeutic means and lifestyle changes. To stop the progression of the disease process, the focus was to be on the use of fluoride (medication), the quality and frequency of toothbrushing/flossing (plaque control), and dietary changes (lifestyle). The lesion was to be identified in the patient's EHR, the proper monitoring codes entered into axiUm, and an appropriate recall time for reassessment created.

Statistical Analysis

Data management and statistical analyses were performed using Stata SE 15.0 at a significance level of 0.05. For descriptive analysis, the distribution of percentages and means were calculated when appropriate. A normality test was used to determine if the data set was well modeled by a normal distribution. Given the fact that most dentists use the restorative threshold of radiographic D1 or even E2 lesions, a logistic regression model was used to correlate radiographic depth, cavitation status, lesion location, and patients' caries risk level for a total of 134 E2 and D1 lesions from 64 patients whose caries risk had been assigned in the EHR. The logistic regression model used caries risk (patient level), type of arch (maxillary/mandibular), tooth surface (mesial/distal), and tooth (incisor, canine, premolar or molar) as independent variables at the levels of lesion and patient. Hence, the model accounted for teeth from the same patient entering the patient in the logistic regression as a variable.

RESULTS

A total of 206 approximal caries lesions from 97 patients (mean average of 2.1 lesions; range of 1 to 16 lesions per patient) were assessed following the protocol for TTS, and information on these lesions was electronically recorded and retrieved for the study analysis. The distribution of these lesions according to location were as follows: 116 (56.6%) were located on distal surfaces and 90 (43.9%) on mesial surfaces; 114 (61.3%) were located on premolars, 40 (21.5%) on molars, 28 (15.1%) on incisors, and 24 (11.7%) on canines; and 137 (66.5%) were

Table 1: *Diagnostic Characteristics and Treatment Recommendations for Approximal Caries Lesions*[a]

Diagnostic Characteristics				Treatment Recommendations
Dental Tissue	**Appearance/Texture**	**Surface Integrity**	**Activity**	
Enamel	• Whitish/yellowish opacity • Shiny surface • Smooth surface upon gentle probing • May exhibit localized shallow defects or microcavitations	Noncavitated	Inactive	• Review oral hygiene instructions, diet, and the use of fluoride • Monitor lesion progression over time
Enamel	• Whitish/yellowish opacity • Loss of luster; 'chalky' or 'milky' appearance • Rough surface upon gentle probing • May exhibit localized shallow defects or microcavitations	Noncavitated	Active	• At the tooth separation visit, apply fluoride varnish while teeth are still separated • Review oral hygiene instructions, diet, and the use of fluoride • Use of at-home fluoride products as part of regular oral hygiene • In-office fluoride varnish applications until lesion activity is controlled (arrested) • Monitor lesion progression over time
Dentin	• Brown or black color • Shiny surface • Hard surface upon gentle probing	Cavitated	Inactive	• Review oral hygiene instructions, diet, and the use of fluoride • Restorative treatment only if compromising the tooth function and the control of lesion activity
Dentin	• Yellow to brown color • Surface breakdown • Soft or leathery texture of exposed dentin	Cavitated	Active	• Review oral hygiene instructions, diet, and the use of fluoride • Restorative treatment

[a] *The color of an inactive lesion may vary from white to brown or black, but color should not be used as a diagnostic characteristic to distinguish active from inactive noncavitated lesions. All treatment recommendations must be accompanied by the management of the patient's caries risk factors.*

located in the maxillary arch and 69 (33.5%) in the mandibular arch.

Table 2 shows the distribution of the lesions according to their radiographic depth and cavitation status. Of the lesions assessed by TTS, 47 (22.8%) were E1, 73 (35.4%) were E2, 74 (35.9%) were D1, and 12 (5.8%) were D2 lesions as determined by radiographic examination prior to TTS. No D3 lesion was assessed by TTS during the study period. After TTS, 92% (n=43) of E1, 90% (n=66) of E2, 66% (n=49) of D1, and 50% (n=6) of D2 lesions were assessed as noncavitated. The logistic regression model showed no significant association between lesion radiographic depth ($p>0.05$) or presence of cavitation ($p>0.05$) with any of the independent variables tested, as shown in Table 3.

DISCUSSION

The most significant findings of this study were that the majority of approximal lesions extending radiographically up to the dentin-enamel junction (E2) and those at the outer third of dentin (D1) were assessed and diagnosed as noncavitated after TTS. Importantly, E2 and D1 lesions are the most likely type of lesions to be restored by dentists when using radiographic examination as the primary method to determine restorative needs.[6] Current evidence supports that treatment strategies should be aimed at arresting carious lesions with intact tooth surfac-

Table 2: *Distribution of Caries Lesions by Radiographic Depth and Surface Cavitation Status as Determined Before and After Tooth Separation, Respectively*[a]

	E1	E2	D1	D2	D3	Total
						
Noncavitated, no. (%)	43 (91.5)	66 (90.4)	49 (66.2)	6 (50)	0	164 (79.6)
Cavitated, no. (%)	4 (8.5)	7 (9.6)	25 (33.8)	6 (50)	0	42 (20.4)
Total, no. (%)	47 (100)	73 (100)	74 (100)	12 (100)	0	206 (100)

[a] *The radiographic depth of caries lesions were recorded as being at the outer (E1) or inner (E2) half of enamel or at the outer (D1), middle (D2), or inner (D3) third of dentin. Percentages are with columns for each lesion depth.*

Table 3: *Logistic Regression Models for Radiographic Lesion Depth and Presence of Surface Cavitation*[a]

Variables	Coefficient	*p*-Value	95% Confidence Interval
Radiographic depth (enamel/dentin)			
Caries risk	0.0767299	0.812	−0.55-0.71
Patient	−0.0125629	0.235	−0.03-0.01
Arch	0.452156	0.574	−1.12-2.03
Tooth type	0.1689549	0.329	−0.17-0.51
Tooth surface	−0.0299411	0.509	−0.12-0.06
Presence of cavitation (yes/no)			
Caries risk	−0.1225252	0.755	−0.89-0.65
Patient	0.0035214	0.785	−0.022-0.03
Arch	0.442721	0.656	−1.50-2.39
Tooth type	−0.2908966	0.143	−0.68-0.10
Tooth surface	0.0352046	0.526	−0.07-0.14

[a] *The logistic regression model used caries risk (extreme, high, moderate, or low), type of arch (maxillary or mandibular), tooth type (incisor, canine, premolar, or molar), and tooth surface (mesial or distal) as independent variables at the levels of lesion and patient.*

es and that restorative intervention should be considered only for cavitated lesions. Based on existing literature, it is not surprising that most E1 lesions were diagnosed as noncavitated.[1] However, the high prevalence of E2 (90%), D1 (66%), and even D2 (50%) lesions diagnosed as noncavitated supports the value of placing orthodontic separators as an effective diagnostic aid for approximal caries lesions. Here, irreversible loss of tooth structure by restorative treatment was prevented in a considerable number of caries lesions based on the accurate assessment of their cavitation status.

Advantages of the TTS technique include low-cost, fast, temporary with reversible separation and the ability to diagnose approximal lesions with sufficient accuracy to support appropriate treatment decisions. Disadvantages may include the fact that occasionally the teeth are not as accessible as needed after the separators are placed, and that the use of the separators may create some brief and mild discomfort for patients. Another disadvantage of this technique is the requirement for an extra office visit if separators are used for longer than 24 hours. While the use of separators for longer periods of time may result in better tooth separation of approximal tooth surfaces, reasonable separation (sufficient to improve assessment) can be achieved when separators are used for a minimum of one hour as described on this study. As this study was performed in an educational setting, further considerations regarding time and work flow must take place when implementing TTS protocols in private and public practice settings. TTS can be performed at any dental visit when the assessment of approximal caries lesions is required, and the separators can remain in the interproximal space while other dental procedures are being performed so as to not disrupt the sequence of the treatment plan. Ideally, the placement of orthodontic bands in the interproximal spaces should be performed as early in the dental appointment as possible to allow more time for tooth separation. If preferable, tooth separators can also remain in place for 24 to 48 hours, but a second dental visit will be required for assessment and removal of the orthodontic bands.

The development and validation of clinical practice protocols or guidelines are necessary to disseminate the best evidence currently available, reduce variability in practice patterns, improve the quality of patient care, and reach consensus among practitioners.[16] A survey-based study revealed that US dental schools use a variety of different approaches to evaluate, select, and implement evidence-based clinical guidelines endorsed by the American Dental Association, and that very few schools were shown to have an effective set of policies and procedures to support guideline implementation.[16]

Undoubtedly, the academic routes to introduce new clinical protocols in an educational setting can have several impediments prior to actual and effective implementation. The development of the TTS protocol described here included the testing of technique feasibility and patients' acceptance in our predoctoral dental clinics, and both were proven acceptable. Notably, patients tolerated the procedure well and were pleased when they were informed that their teeth did not have a cavity and that no "drilling and filling" were needed.

The use of EHR can facilitate careful documentation of the diagnosis, treatment plan, and monitoring plans for caries lesions. Our electronic-based protocol for TTS was developed using axiUm, but it is anticipated that a similar protocol can be developed and adapted for other software programs. The use of our electronic-based protocols and tracking systems can certainly facilitate data collection to support evidence on the use of TTS as a diagnostic aid for approximal caries lesions, and they may also contribute to a reexamination of the optimal threshold for restorative intervention on approximal lesions. This information will also be useful to track compliance and to provide feedback to students and faculty about their own personal implementation of the clinical protocol.

Caries risk assessment is key to the success of the caries management plan. However, according to our TTS protocol, treatment recommendations for approximal caries lesions are based on lesion cavitation status and activity as determined by the TTS procedure and shown in Table 1, and not based on the patient's caries risk level. Treatment recommendations should also take into consideration the patients' needs, risks, motivation and compliance capabilities. Of great importance, dental care providers should explain the treatment options for individual lesions (nonsurgical and/or surgical approaches) to patients and provide the necessary educational resources for patients to choose the treatment option that best aligns with their unique cultural and personal beliefs and lifestyles. Effective patient participation and engagement in a shared decision-making process certainly support the compliance and promotion of dental health. Regardless of the treatment decision, there must be a rigorous and specific strategy in place for assessing and monitoring caries activity and lesion progression over time. It is even more critical to closely monitor the activity of noncavitated approximal lesions to evaluate whether the management recommendations based on nonsurgical approaches have been effective at arresting these lesions. Diagnostic codes and electronic forms were developed to create a monitoring plan for active approximal caries lesions that were assessed as noncavitated after tooth separation. At each recall visit, lesion activity and cavitation status must be reassessed, at-home preventive recommendations should be reinforced, and treatment approaches should be reevaluated as needed. Effective patient participation and engagement in a shared decision-making process will certainly facilitate compliance with treatment recommendations and successful promotion of dental health.

Although robust evidence exists supporting risk-based and tooth-preserving approaches for caries management, evidence for long-term clinical outcomes of noncavitated lesions assessed by tooth separation is lacking. Only one longitudinal study reported a range of 20% to 44% in cavitation prevalence of dentin lesions after two years of recall visits (six-month interval) but with limited preventive intervention.[11] It can be argued that the scientific basis for many of the "newer" caries management approaches is not yet validated, but neither is the scientific basis for many of the surgical procedures done in dentistry.[17] As previously discussed in different venues, when the well-being of the patient is considered, it is more important to carry out a risk-based caries management plan incorporating the best available evidence than to do nothing due to the lack of strong evidence.[6, 18]

CONCLUSIONS

Findings from this study support that the use of temporary tooth separation is in line with the tooth-preserving philosophy of modern caries management, and that it is a feasible and effective diagnostic aid for assessment and appropriate management of approximal caries lesions. There is a clear need to reevaluate the use of radiographic lesion depth as the single determinant of the restorative threshold for clinically inaccessible approximal lesions.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the Institutional Review Board of the University of Florida. The approval code issued for this study is IRB201800458.

Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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