

Exploring How U.S. Dental Schools Teach Removal of Carious Tissues During Cavity Preparations

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Abstract: Approaches for managing carious tissues during cavity preparations vary considerably among clinicians, which may reflect inconsistencies in the teaching of this subject by dental schools. The aims of this study were to investigate practices related to the preclinical and clinical teaching of caries removal at U.S. dental schools and the relationship between that teaching and requirements for U.S. dental licensure examinations. The electronic survey included questions about terminology, methods, instruments and materials, treatment planning, criteria for clinical exams, faculty calibration sessions, and licensure exams. The faculty members at U.S. dental schools responsible for teaching cariology were invited to participate; 54 of the 65 schools had identified a contact person at the time of the survey in October 2015. Of those 54 invited to participate, 43 completed the survey (response rate of 79.6%). Most of the respondents indicated that depth of carious lesions was a clinical determinant of the amount of carious dentin being removed in cavity preparations. Caries removal was used as a criterion in restorative clinical examinations by 95% of responding schools. Marked differences were observed regarding the criteria used for assessment and removal of carious tissues, management of deep carious lesions, and definition of “caries remaining at cavity preparations,” which is considered a critical error on licensure exams. Faculty calibration sessions on caries removal were reported to occur in 65% of these schools and at different time frames. Overall, the study found a wide range of teaching practices related to caries removal. Best evidence in caries management needs to be aligned with teaching and the criteria used to calibrate faculty members and examiners.

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Keywords: dental education, dental caries, caries management, caries removal, cariology

Submitted for publication 7/15/16; accepted 9/20/16

The development of carious lesions involves a dynamic biological process in which acids produced by bacterial glycolysis of dietary carbohydrates in oral biofilms cause demineralization of dental hard tissues. The advanced stages of lesion progression are characterized by continuous metabolic activity and penetration of oral bacteria into the dentin and are often associated with the presence of tooth cavitation. Restorative dentistry is the science and practice of reestablishing the integrity and function of the tooth, so that the patient can effectively remove oral biofilms (also called dental plaque) and therefore control the caries process.¹ Importantly, restorative dentistry, which includes treatment of

primary carious lesions and replacement of defective restorations, represents the bulk of treatment offered by general practitioners.² Once the clinical decision has been made to place a dental restoration, dental clinicians have to determine how much of the carious tissues should be removed. Although morphological studies have shown a defined boundary between the highly infected and the caries-affected dentin,^{3,4} clinically this situation presents a subjective and difficult decision for the practitioner regarding the amount of carious dentin that should be removed.

The contemporary practice of caries removal based on clinical evidence supports a minimally invasive approach in which only the infected dentin

and not the affected dentin should be removed during cavity preparations. Furthermore, removal of carious tissues should be even more conservative in a deep caries lesion where there is a healthy pulp. This approach preserves tooth structure and avoids pulpal exposure, especially in deep or extensive carious lesions. This evidence-based practice is a paradigm shift away from the traditional and long-standing restorative approach of removing all carious tissues until hard and perhaps unstained dentine is reached in all structures of cavity preparations. However, the approaches for managing carious tissues vary considerably among clinicians.⁵ Previous studies assessing dentists' attitudes and treatment decisions about deep carious lesions showed a lack of uniform treatment methods and that the majority of surveyed dentists remained skeptical about partial caries removal techniques.⁶⁻⁹ Moreover, there is a wide range of beliefs and practices among dental schools and faculty members with regards to the terminology used to differentiate types of carious tissues, techniques used for excavation and removal of carious tissues, and caries management and restorative dentistry philosophies. In this context, cariology experts have recently attempted to reach consensus on the terminology and clinical recommendations for managing carious tissues during cavity preparations.^{10,11}

Also of concern is how the management of carious tissues during cavity preparations is assessed during clinical licensure examinations. The current system of clinical licensing exams for dental practice in the U.S. has been questioned for many years.¹²⁻¹⁵ There is considerable variation in requirements among the state/regional testing agencies and boards of dental examiners.¹⁵ Currently, the restorative section is still a patient-based exam in which candidates are evaluated on anterior and posterior tooth preparations and restorations. One of the most controversial errors contributing to failure of the restorative exam is "caries remaining" during cavity preparations. The American Board of Dental Examiners (ADEX) describes caries remaining at cavity preparations as dentin that is soft and penetrable by light pressure with an explorer.¹⁶ The Western Regional Examining Board (WREB) describes affected dentin as dentin that is slightly penetrable by sharp explorer and requests that all caries, unsound demineralized enamel, and affected dentin be totally removed except that directly over the pulp chamber, which if removed would result in pulp exposure.¹⁷ Demineralized enamel is considered unsound by WREB if it is tactilely different from the adjacent unaffected enamel. The Central Regional Dental Testing Service (CRDTS)

also considers decalcified enamel margins that can be penetrated by an explorer and/or that which exceeds half the thickness of enamel as a critical error.¹⁸ Of even greater importance is that the inherent subjective clinical assessment of carious enamel and dentin during board exams may encourage excessive removal and thus overpreparation of dental tissues. Clearly, best evidence in caries management needs to be aligned with the criteria used to calibrate examiners and during the evaluation of examinees.

To further explore these issues, the first aim of this study was to investigate practices related to the preclinical and clinical teaching of management of carious tissue during cavity preparations at U.S. dental schools. The second aim was to investigate whether there was an association between the teaching of this topic and the requirements for U.S. dental licensure examinations related to the management of carious tissues during cavity preparations.

Methods

The Institutional Review Board of the University of Florida approved this study (IRB02 #201500960). The participants we sought for the study were the faculty members responsible for preclinical and/or clinical teaching of cariology at U.S. dental schools. To identify the appropriate individual, a contact list by school was obtained in October 2015 from the American Dental Education Association (ADEA) Section on Cariology. This list was developed with help from the schools and contained contacts for 54 of the 65 U.S. dental schools. The remaining 11 schools had not yet identified a main cariology contact. The faculty members responsible for cariology education at 54 dental schools were invited to participate in the electronic survey via email using SurveyMonkey.

The 31 questions on the author-developed survey asked about the following related to caries removal: terminology; preclinical and clinical teaching, including methods used and criteria for clinical examinations; treatment planning; and dental licensure examinations taken by the schools' graduates. In addition, several of the survey questions had an open answer option (e.g., "Others, please specify") for respondents to provide any further information or comments.

Data were collected using the professional level version of SurveyMonkey to allow for better data security through SSL encryption. Only the investigators had access to the aggregated findings; no

response identifiers were used. The identity of each faculty member and his or her school was excluded from the analysis. Descriptive analysis was the major analytical method used.

Results

Of the cariology contact faculty members at 54 schools invited to participate, 43 completed the survey (response rate of 79.6%). On some questions, not all 43 responded. Therefore, the total number of responses did not consistently equal 43.

Terminology

The first set of questions related to terminology. Most of the respondents (>75%) reported that their school routinely used the terms “demineralized enamel,” “decalcified enamel,” “demineralized dentin,” “cariou dentin,” “infected dentin,” “affected dentin,” “complete caries removal,” and “partial caries removal” (Table 1). Among the comments received were the following: “We routinely use the term ‘caries’ vs. ‘cariou enamel’”; and “Terminology is all across the board. More commonly, they call everything with the term ‘caries.’ This causes confusion with the students and may also lead to overtreatment surgically.”

The definitions used for “infected” and “affected” dentin were examined. A total of 37 (86.1%) respondents indicated their school used this definition for “infected dentin”: “the irreversible demineralized and denatured layer of dentin, not reparable, and with bacterial invasion; it feels very soft, moist, and easy to remove with a spoon excavator.” Four of the respondents (9.3%) indicated using this definition but

with some modifications, and two (4.6%) reported not using the definition of infected dentin. Comments related to this question included the following: “We only use the term ‘cariou dentin’”; and “It [infected dentin] is not always very soft, moist. There are gradations of softness and moistness but would still be considered infected.”

A total of 31 (72.1%) respondents indicated their school used this definition for “affected dentin”: “the partially and reversibly demineralized dentin that contains minimal to no bacteria; it feels leathery and softer than normal/sound dentin upon use of spoon excavator. Affected dentin can be penetrated by an explorer.” Ten (23.3%) indicated using this definition but with some modifications, and two (4.6%) reported not using the definition of affected dentin. Comments included the following: “We are using the definition but not advocating the penetration by the explorer”; and “We use the term ‘leathery cariou dentin.’ Not sure how you accurately identify such an affected layer with minimal or no bacteria clinically. How much bacteria is too much, and how do you identify that level clinically?”

Teaching Methods and Exams

The majority of the respondents (36; 83.7%) indicated their school had one or more sessions of preclinical simulation laboratory on caries removal, which included the use of extracted cariou teeth (at 29 schools; 80.6%) and/or caries-simulated plastic teeth (18; 50.0%) and/or others (3; 8.3%). The “Others” category included the use of regular plastic teeth and the use of Simodont Dental Trainer equipment (ACTA, Amsterdam, The Netherlands).

When asked if the didactic and preclinical teaching of caries removal at their school was con-

Table 1. Terminology routinely used during preclinical and clinical teaching of caries removal, by number and percentage of respondents for each term

Term	Yes	No	Total
Demineralized enamel	40 (93.0%)	3 (7.0%)	43 (100%)
Decalcified enamel	30 (75.0%)	10 (25.0%)	40 (100%)
Cariou enamel	28 (71.8%)	11 (28.2%)	39 (100%)
Demineralized dentin	39 (90.7%)	4 (9.3%)	43 (100%)
Cariou dentin	43 (100%)	0	43 (100%)
Infected dentin	40 (93.0%)	3 (7.0%)	43 (100%)
Affected dentin	38 (88.4%)	5 (11.6%)	43 (100%)
Complete caries removal	42 (97.7%)	1 (2.3%)	43 (100%)
Partial caries removal	37 (88.1%)	5 (11.9%)	42 (100%)
Incomplete caries removal	29 (70.7%)	12 (29.3%)	41 (100%)
Stepwise excavation	28 (68.3%)	13 (31.7%)	41 (100%)

sistent with the clinical instructions received by students, 30 (71.4%) of the respondents reported yes, and 12 (28.6%) no. The survey also asked if and how often the schools scheduled faculty calibration sessions on the topic of caries removal. While 26 (65.0%) of the respondents reported having calibration sessions at their schools, 14 (35.0%) reported they did not. A broad range of time between faculty calibration sessions was reported: from “three times per year” to “every 3 to 4 years” to on an “as needed basis.”

“Caries removal” was reported to be used as a criterion in restorative clinical examinations (e.g., competencies) at most of the participating schools (40; 95.2%). “Caries remaining at cavity preparations” is considered a critical error by most U.S. dental licensure testing agencies and board of examiners and is commonly defined as a) the demineralized/decalcified enamel margins that can be penetrated by an explorer and/or exceed half the thickness of enamel and b) the affected dentin that is slightly penetrable by sharp explorer. The same definition of “caries remaining” was reported to be considered a critical error in restorative clinical examinations at 19 (45.2%) of the schools, whereas 20 (47.6%) used a slightly different definition and three (7.2%) reported not using this criterion. Comments related to the use of “caries remaining” as a criterion on clinical examinations included: “Students must state that they are intentionally leaving affected carious tissue in the cavity preparations”; and “We are not well calibrated on this issue! This includes the use of a sharp explorer to penetrate anything in a tooth.”

A total of 31 (73.8%) of the respondents indicated their schools allow demineralized/decalcified enamel margins to remain in cavity preparations that will be further restored with adhesive materials. The respondents reported their schools used the following methods to assess the status of enamel margins in cavity preparations: visual examination (used by

100% of the participating schools), tactile examination by the use of an explorer (88.1%), and tactile examination by the use of an excavator (68.2%).

Table 2 shows the frequency of the methods, materials, and dental instruments reported to be routinely used for removal of carious dentin in cavity preparations and for arrestment of carious lesion progression. Most of the respondents reported their schools routinely used hand excavator (41; 97.6%) and metal burs (39; 95.2%) for removing carious dentin in cavity preparations; only two reported using plastic burs (5.4%), and none indicated using ceramic burs. Some respondents reported their schools used caries dye indicator (14; 33.3%). Only two reported using a chemical-mechanical, enzyme-based technology (5.6%). The application of silver-diamine fluoride for arrestment of primary caries (4; 9.5%) or inside cavity preparations to harden carious dentin (1; 2.4%) was also reported infrequently.

The majority of the respondents (31; 73.8%) indicated that, at their schools, the depth of carious lesions is a clinical determinant of the amount of carious dentin being removed in a cavity preparation; more specifically, the amount of carious tissue being removed differed between shallow and deep carious lesions. Shallow, dentin carious lesions were defined radiographically as D1 lesions at 36 schools (85.7%) and/or as D2 lesions at 13 schools (31.0%) and/or as “Others” at eight schools (19.1%). Comments regarding the definition of shallow dentinal lesions included the following: “[Lesions that are] less than 1/3 into dentin towards the pulp”; and “There is no consistency in how shallow or deep is defined and treated.” Deep, dentinal carious lesions being defined radiographically as D2 lesions was reported at 12 schools (28.6%) and/or as D3 lesions at 36 schools (85.7%) and/or as “Others” at eight schools (19.1%). Regarding the definition of deep dentin lesions, one participant commented, “[Lesions that are] more than 2/3 into dentin towards the pulp.”

Table 2. Frequency of methods, materials, and instruments used for removal of carious dentin and/or for arrestment of carious lesion progression, by number and percentage of respondents on each item

Item	Yes	No	Total
Hand excavator	41 (97.6%)	1 (2.4%)	42 (100%)
Metal burs	39 (95.2%)	2 (4.8%)	41 (100%)
Plastic burs	2 (5.4%)	35 (94.6%)	37 (100%)
Ceramic burs	0	36 (100%)	36 (100%)
Chemical-mechanical, enzyme-based technology (e.g., Carisolv, Papacarie)	2 (5.6%)	34 (94.6%)	36 (100%)
Caries dye indicator	14 (33.3%)	28 (66.7%)	42 (100%)
Silver-diamine fluoride for arrestment of primary caries	4 (9.5%)	38 (90.5%)	42 (100%)
Silver-diamine fluoride inside cavity preparations to harden carious dentin	1 (2.4%)	41 (97.6%)	42 (100%)

Table 3 shows the use of hardness, color, and moisture of carious tissues as criteria to assess satisfactory removal of carious dentin in shallow and deep carious lesions. In terms of hardness, a greater percentage of respondents (37; 88.1%) reported their schools considered that the floor of the cavity must feel hard in shallow lesions. However, there was less agreement with regards to deep lesions. Respondents reported that, at their schools, the floor must feel either hard (9; 45.2%) or leather-like (18; 42.8%). The color of dentin was reported to have no influence on the tissue excavation in shallow lesions at 23 schools (54.8%) and in deep lesions at 29 schools (69.1%). Yet, several respondents reported that satisfactory removal at their schools is confirmed when the floor of the cavity has normal dentin color to yellowish color in shallow (17; 40.5%) and deep lesions (9; 21.4%) or when the floor of the cavity is dark stained in shallow (2; 4.8%) and deep lesions (4; 9.5%). The moisture of dentin was also reported to have no influence on excavation in shallow (19 schools; 45.2%) and deep (16; 38.1%) lesions. However, several respondents reported that, at their schools, the floor of the cavity must be dry in shallow (19; 45.2%) and deep (10; 23.8%) lesions, while few reported that the floor of the cavity could be a little moist or very moist in shallow (4; 9.5%) and deep (16; 38.1%) lesions. Comments regarding criteria used to assess removal of carious dentin included the following: “Color [is used as a criterion] only at the DEJ; we want to change, but difficulty convincing all clinical faculty”; “We use hardness [as a criterion] on periphery of the lesion, 2 mm from DEJ”; “Extremely variable and inconsistent in our clinical instruction! Not at all calibrated”; and “Clinical faculty are not well calibrated, so there is no consistency in how shallow or deep is defined and treated.”

Treatment Planning

A case scenario was presented on the survey in which pulp exposure occurred during excavation of a deep carious lesion on a symptomatic or an asymp-

tomatic patient. Respondents were asked to describe what would be the routine treatment of choice for this tooth at their schools. Options were root canal treatment, partial pulpotomy, or direct pulp cap. On a symptomatic patient, 39 (92.9%) respondents reported their schools would perform root canal treatment, one (2.4%) partial pulpotomy, and two (4.7%) direct pulp cap. On an asymptomatic patient, six (14.3%) respondents reported their schools would perform root canal treatment, two (4.7%) partial pulpotomy, and 34 (81.0%) direct pulp cap.

Another case scenario asked participants to respond to the treatment options for an asymptomatic vital tooth with a deep carious lesion on a 20-year-old patient (Table 4). Over half of the respondents (24; 57.1%) reported that their schools would perform a partial caries removal as the main treatment option for this tooth and that, if there was a risk for pulp exposure, to leave some carious dentin close to the pulp and perform a permanent restoration. Of the schools that used stepwise excavation (two steps), a separate question asked about the time for re-entering the tooth. Responses chosen were divided among three options: between two weeks and three months (3; 37.5%), after three months and up to six months (3; 37.5%), and more than six months (2; 25%). Comments regarding this case scenario included the following: “Although the students are taught to perform partial caries removal during cariology, I often witness aggressive excavation, and often they do create pulpal exposures”; “Complete caries removal is first option; then a clinical decision is made for an indirect pulp cap with permanent or sedative filling if there is less than 0.5 mm of dentin and remaining active, carious dentin”; and “Generally, aim for total caries removal; however, if deep, affected dentin may remain with sealed margins for permanent restorations.”

The survey also included 12 statements related to the teaching of caries removal and the assessment of “caries remaining” during licensure examinations. Respondents were asked to indicate their opinions

Table 3. Frequency of use of criteria used to assess sufficient removal of carious dentin during cavity preparations, by number and percentage of respondents on each criterion

Criterion	Shallow Lesions			Deep Lesions		
	Yes	No	Total	Yes	No	Total
Hardness	42 (100%)	0	42 (100%)	38 (90.5%)	4 (9.5%)	42 (100%)
Color	24 (58.5%)	17 (41.5%)	41 (100%)	22 (56.4%)	17 (43.6%)	39 (100%)
Moisture	22 (55.0%)	18 (45.0%)	40 (100%)	28 (68.3%)	13 (31.7%)	41 (100%)

Table 4. Treatment for asymptomatic vital tooth with deep carious lesion on a 20-year-old patient, by number and percentage of respondents who chose each option

Treatment Option	Yes
Perform total caries removal; if there is a small pulpal exposure, perform a direct pulp cap	5 (11.9%)
Perform total caries removal; if there is a small pulpal exposure, perform root canal treatment	1 (2.4%)
Perform partial caries removal; if there is a risk of pulp exposure, leave some carious dentin close to the pulp, and perform a permanent restoration	24 (57.1%)
Perform total caries removal in two steps (stepwise excavation); if there is a risk of pulp exposure, leave some carious dentin close to the pulp, and then finish the caries removal a few weeks or months later	8 (19.1%)
Other	4 (9.5%)

using a Likert scale, with options from strongly disagree to strongly agree (Table 5).

Licensure Examinations

The survey gathered information about the most common state/regional testing agencies or boards of dental examiners taken by the dental schools' graduates. The number of respondents reporting each of the licensure examinations most commonly taken by their schools' graduates were as follows: 13 (32.5%) the Commission for Dental Competency Assessments (CDCA); 12 (30.0%) WREB; five (12.5%) CRDTS; three (7.5%) the Council of Interstate Testing Agencies (CITA); one (2.5%) the Southern Regional Testing Agency (SRTA); and six (15.0%) others. Two comments provided under the "others" category were "50% WREB, 50% CDCA" and "The North East Regional Board (NERB) or ADEX." The estimated annual percentages of graduates who had failed dental licensure examinations due to "caries remaining" in the past five years were as follows: less than 1% for eight (20%) schools, 1-10% for 16 schools (40%), and >30% for one school (2.5%). The remaining 15 (37.5%) respondents reported that they did not know or did not have access to this information for their schools (Table 6).

Discussion

The findings from this study indicate that there is substantial inconsistency among U.S. dental schools with regards to the preclinical and clinical teaching of caries removal during cavity preparations. Specifically, the variations observed in the criteria used for assessment of carious tissues, clinical protocols for caries removal, and management of deep carious lesions showed a profound lack of consensus, confusion on terminology, and issues with adoption

of best evidence in this area among schools. This lack of consensus may be somewhat justified by the absence of methods to easily, reproducibly, and objectively differentiate carious tissues (or measure caries removal) and/or insufficient information available about the clinical outcomes of the treatments provided¹⁹ and/or the scarce translation of evidence-based knowledge from research to teaching and thus to clinical practice. A concern voiced in 1908 and quoted by Fejerskov seems still relevant: "The complete divorcement of dental practice from studies of the pathology of dental caries that existed in the past is an anomaly in science that should not continue. It has the apparent tendency to make dentists mechanics only."²⁰ Apparently, the same concern remains today regarding the teaching of cariology in the U.S.

The successful management of a disease such as dental caries relies on the understanding of its etiological factors. Caries is well established as a pH-driven and ecologically dependent biofilm disease. If the biological aspects of caries are not well emphasized during predoctoral dental education, then bias towards mechanical intervention may prevail as the treatment of choice for caries management. Our study found that in many dental schools there is a prominent lack of an evidence-based educational philosophy in the teaching of caries removal. In such situations, it is likely that the clinical practices adopted by dental students may therefore be more influenced by personal opinions and mechanical philosophy rather than by scientific evidence for their efficacy and safety.

Participant comments on the survey showed that current caries terminology routinely used in preclinical and clinical teaching in U.S. dental schools varied widely. This variation is likely to cause confusion among students and lead to surgical overtreatment. Ensuring that there is consistent, accurate, and precise communication as it relates to terminology is

Table 5. Opinions, beliefs, and curricula of survey respondents, by number and percentage of total respondents (n=40)

Statement	Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree
Infected dentin (very soft, moist) must always be entirely removed; otherwise, the caries lesion will progress under the restoration.	6 (15.0%)	8 (20.0%)	0	14 (35.0%)	12 (30.0%)
Affected dentin (leathery, penetrable with explorer) must always be entirely removed; otherwise, the caries lesion will progress under the restoration.	21 (52.5%)	14 (35.0%)	0	4 (10.0%)	1 (2.5%)
A certain amount of affected dentin, and therefore microorganisms, can be left under the restoration because the caries lesion will not progress if it is well sealed.	2 (5.0%)	1 (2.5%)	3 (7.5%)	11 (27.5%)	23 (57.5%)
The carious dentin must be completely removed because it presents a danger to the vitality of the pulp.	17 (42.5%)	15 (37.5%)	2 (5.0%)	5 (12.5%)	1 (2.5%)
In the case of a deep caries lesion in an asymptomatic patient, dental tissue close to the pulp must be preserved to avoid pulp exposure.	0	5 (12.5%)	1 (2.5%)	10 (25.0%)	24 (60.0%)
If the preparation margins are in enamel, then sound enamel margins (no signs of decalcification) are required for best performance of adhesive restorative materials.	3 (7.5%)	2 (5.0%)	0	15 (37.5%)	20 (50.0%)
If the preparation margins are in dentin, then sound dentin margins (hard dentin) are required for best performance of adhesive restorative materials.	1 (2.5%)	3 (7.5%)	3 (7.5%)	14 (35.0%)	19 (47.5%)
The DEJ should have sound dental tissues (no signs of decalcified enamel and hard dentin) for best performance of adhesive restorative materials.	1 (2.5%)	4 (10.0%)	1 (2.5%)	17 (42.5%)	17 (42.5%)
Irrespective of lesion depth, the excavation of carious dentin should aim to remove the infected dentin while being minimally invasive through maximum preservation of the affected dentin within the cavity preparation.	2 (5.0%)	6 (15.0%)	5 (12.5%)	10 (25.0%)	17 (42.5%)
The inherent subjectivity in detecting the dentin excavation boundary can result in clinically significant differences in the quality and quantity of dentine removed by different operators.	1 (2.5%)	1 (2.5%)	2 (5.0%)	15 (37.5%)	21 (52.5%)
The inherent subjective clinical assessment of carious enamel and dentin during board examinations may encourage excess removal and thus overpreparation of dental tissues.	0	1 (2.5%)	2 (5.0%)	5 (12.5%)	32 (80.0%)

crucial across the spectrum of clinicians, educators, and researchers. To promote consistency, the International Caries Consensus Collaboration (ICCC)'s terminology to describe clinical management of carious lesions, published in 2016, should serve as a starting point for U.S. dental schools.¹⁰

When the participants in our study were questioned about the use of hardness as a criterion to assess satisfactory removal of carious dentin in carious lesions, the great majority reported that the floor of the cavity must feel hard in shallow lesions. Almost half of the respondents reported that the floor of the cavity must feel hard, whereas the other half reported that it must feel leathery in deep lesions. Generations of dentists have removed all infected enamel and dentin using excavators or high- and low-speed instruments, thus risking exposure of the pulp. Today, there is enough clinical evidence to discourage complete removal of all carious tissues during cavity preparations.^{1,21} Strong evidence supports the incomplete removal of carious tissue before the cav-

Table 6. Estimated percentage of graduates at participating schools who failed dental licensure exams due to "caries remaining" in past five years, by number and percentage of total respondents (n=40)

Annual Percentage	Respondents
<1%	8 (20.0%)
1-10 %	16 (40.0%)
10-30%	0
>30%	1 (2.5%)
I do not know or do not have access to this information.	15 (37.5%)

ity is restored, irrespective of lesion depth, provided that the tooth is asymptomatic.¹¹ Clinical trials have shown considerable reduction of pulpal exposure and postoperative pulpal complications for incomplete compared with complete caries removal.^{19,22,23} The reparative processes of tubular sclerosis and tertiary dentine are encouraged, thus reducing the permeability of the remaining dentine.¹ Narrowing or complete

obliteration of the pulpal space can occur in coronally restored teeth,²⁴ which may represent a challenge to locate the root canals if endodontic therapy becomes necessary. However, up to 75% of teeth with pulp canal obliterations are reported to be symptom-free and require no treatment other than radiographic monitoring.²⁵ If the restoration placed seals the cavity and allows for regular plaque removal, then infected and partially softened dentin may be left because the caries process will not continue.^{12,19-23} This is possible because the bacteria inside of the cavity will become inactivated due to the absence of carbohydrates to serve as nutrient sources for bacterial growth and for acid production that would otherwise demineralize the tooth tissues. Hence, restorative dentistry should focus less on complete removal of carious tissues and more on accurate understanding of the caries tissue management to provide adequate placement of long-term restorations.¹

Using this rationale, the ICCC recently agreed on the term “selective caries removal.”^{10,11} In selective removal, different excavation criteria are used when assessing the periphery of the cavity to the area that is in close proximity to the pulp. In light of the increased practice of adhesive dentistry, studies have shown that many bonding systems are well suited for restoring demineralized enamel and affected dentin.^{26,27} However, what is clinically recommended in those studies is to finish the cavity margins in clean/sound enamel and/or dentinal tooth tissue in order to achieve the best performance of adhesives, while being least invasive with regard to caries excavation and most conservative with regard to sound-tissue preservation. The dentine at the cavity margins should be hard, with similar tactile characteristics to sound dentine.^{10,11} Firm carious tissue should be left toward the pulpal aspect of the cavity, although enough of it should be removed to allow a durable bulk of restoration to be placed while avoiding pulp exposure. In the consensus of cariology experts, “For deep lesions, extending beyond the inner [pulpal] third or quarter of the dentine radiographically, selective removal should be to soft dentine; the main aim is not to expose or irritate the pulp, provided that there are no clinical symptoms of pulp inflammation present. For less deep lesions, selective removal should take place to firm dentine pulpally; this is likely to be necessary to allow adequate depth for the restorative material bulk.”¹¹

Our study also asked respondents about the occurrence and frequency of faculty calibration sessions at their schools. Again, there was great variability

among the responses. Inconsistencies in teaching among peers within the same school were also mentioned in the survey comments. To ensure better communication with students and to facilitate their acquisition of evidence-based knowledge, it is critical that faculty members use the same terminology and clinical protocols consistently while teaching. We suggest that the survey used in this study (available from the corresponding author) be a starting point for discussions among schools’ faculty members regarding removal of carious tissues in association with literature review sessions, which should include the ICCC reports.^{10,11} In addition, recent efforts have been made to develop a core curriculum framework in cariology for U.S. dental schools.²⁸ This framework can serve as a resource for improving and aligning current evidence with the teaching of cariology.

Limitations of this study are those often found in one-time administration of a survey such as lack of a control group, reliance on a convenience sample, and use of a non-validated instrument. Also, respondents may not provide honest and accurate responses. Closed-ended questions may have a lower validity rate than other question types. Future studies should explore the pre and post beliefs and attitudes of faculty members who participate in calibration sessions to help educators discern the degree to which such sessions lead to changes and if different teaching strategies are needed for calibration. Other research could ask how many sessions it takes to calibrate faculty to 90% agreement on teaching the removal of carious tissues during cavity preparation. Also, studies could correlate the degree of faculty calibration with student pass rates on national boards. Finally the use of semi-structured interviews could provide greater insight into the practice beliefs of the restorative faculty.

The National Board Dental Examination (NBDE) uses standardized tests to evaluate the educational preparedness of individuals for the practice of dentistry. In the past five years, our study found that up to 10% of students in 24 of the 40 participating dental schools failed a licensure exam due to “caries remaining in cavity preparations.” Perhaps the degree of variability in terminology and lack of evidence-based clinical protocols for the management of carious tissue removal played a critical role in these outcomes. Consistency, accuracy, and precision in terminology for the removal of carious tissues are important to implementing standardized training for students and for calibrating board examiners and dental educators. Our findings should help catalyze development and

distribution of guidelines to standardize the teaching of concepts and the practice of conservative, evidence-based caries removal across the U.S.

Conclusion

This study found a wide range of teaching practices related to caries removal among U.S. dental schools. The subjective clinical assessment of carious tissues during school and licensure examinations may encourage excess removal and thus overpreparation of dental tissues. Best evidence in caries management needs to be aligned with teaching and the criteria used to calibrate faculty members and examiners when evaluating student performance.

Acknowledgments

This project was supported in part by the Health Resources and Services Administration (HRSA) of the U.S. Department of Health and Human Services (HHS) under (# 1 D86HP24477-01-00). This information or content and conclusions are those of the authors and should not be construed as the official position or policy of, nor should any endorsements be inferred by, HRSA, HHS, or the U.S. government.

Disclosure

The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

REFERENCES

1. Kidd EA. How “clean” must a cavity be before restoration? *Caries Res* 2004;38(3):305-13.
2. Nascimento MM, Gordan VV, Qvist V, et al. Reasons for placement of restorations on previously unrestored tooth surfaces by dentists in the dental practice-based research network. *J Am Dent Assoc* 2010;141(4):441-8.
3. Fusayama T. Two layers of carious dentin: diagnosis and treatment. *Oper Dent* 1979;4(2):63-70.
4. Maltz M, de Oliveira EF, Fontanella V, Bianchi R. A clinical, microbiologic, and radiographic study of deep caries lesions after incomplete caries removal. *Quintessence Int* 2002;33(2):151-9.
5. Schwendicke F, Paris S, Tu YK. Effects of using different criteria for caries removal: a systematic review and network meta-analysis. *J Dent* 2015;43(1):1-15.
6. Oen KT, Thompson VP, Vena D, et al. Attitudes and expectations of treating deep caries: a PEARL network survey. *Gen Dent* 2007;55(3):197-203.
7. Schwendicke F, Meyer-Lueckel H, Dorfer C, Paris S. Attitudes and behavior regarding deep dentin caries removal: a survey among German dentists. *Caries Res* 2013;47(6):566-73.
8. Stangvaltaite L, Kundzina R, Eriksen HM, Kerosuo E. Treatment preferences of deep carious lesions in mature teeth: questionnaire study among dentists in northern Norway. *Acta Odontol Scand* 2013;71(6):1532-7.
9. Weber CM, Alves LS, Maltz M. Treatment decisions for deep carious lesions in the Public Health Service in Southern Brazil. *J Public Health Dent* 2011;71(4):265-70.
10. Innes NP, Frencken JE, Bjorndal L, et al. Managing carious lesions: consensus recommendations on terminology. *Adv Dent Res* 2016;28(2):49-57.
11. Schwendicke F, Frencken JE, Bjorndal L, et al. Managing carious lesions: consensus recommendations on carious tissue removal. *Adv Dent Res* 2016;28(2):58-67.
12. Abdelkarim A, Sullivan D. Attitudes and perceptions of U.S. dental students and faculty regarding dental licensure. *J Dent Educ* 2015;79(1):81-8.
13. Formicola AJ, Shub JL, Murphy FJ. Banning live patients as test subjects on licensing examinations. *J Dent Educ* 2002;66(5):605-9.
14. Lantzy MJ, Muzzin KB, DeWald JP, et al. The ethics of live patient use in dental hygiene clinical licensure examinations: a national survey. *J Dent Educ* 2012;76(6):667-81.
15. Ranney RR. What the available evidence on clinical licensure exams shows. *J Evid Based Dent Pract* 2006;6(1):148-54.
16. Candidate manual: ADEX dental examination. Mesa, AZ: American Board of Dental Examiners, Inc., 2014.
17. WREB 2015 dental exam candidate guide. Phoenix, AZ: Western Regional Examining Board, 2015.
18. CRDTS dental examination candidate manual. Topeka, KS: Central Regional Dental Testing Service, Inc., 2015.
19. Ricketts D, Lamont T, Innes NP, et al. Operative caries management in adults and children. *Cochrane Database Syst Rev* 2013(3):CD003808.
20. Fejerskov OKE. Caries removal and the pulpo-dentinal complex. In: *Dental caries: the disease and its clinical management*. 2nd ed. New York: Blackwell, 2008:367-82.
21. Thompson V, Craig RG, Curro FA, et al. Treatment of deep carious lesions by complete excavation or partial removal: a critical review. *J Am Dent Assoc* 2008;139(6):705-12.
22. Ricketts DN, Kidd EA, Innes N, Clarkson J. Complete or ultraconservative removal of decayed tissue in unfilled teeth. *Cochrane Database Syst Rev* 2006(3):CD003808.
23. Schwendicke F, Dorfer CE, Paris S. Incomplete caries removal: a systematic review and meta-analysis. *J Dent Res* 2013;92(4):306-14.
24. Fleig S, Attin T, Jungbluth H. Narrowing of the radicular pulp space in coronally restored teeth. *Clin Oral Investig*, July 10, 2016.
25. McCabe PS, Dummer PM. Pulp canal obliteration: an endodontic diagnosis and treatment challenge. *Int Endod J* 2012;45(2):177-97.
26. de Almeida Neves A, Coutinho E, Cardoso MV, et al. Current concepts and techniques for caries excavation and adhesion to residual dentin. *J Adhes Dent* 2011;13(1):7-22.
27. Perdigao J. Dentin bonding variables related to the clinical situation and the substrate treatment. *Dent Mater* 2010;26(2):e24-37.
28. Fontana M, Guzman-Armstrong S, Schenkel AB, et al. Development of a core curriculum framework in cariology for U.S. dental schools. *J Dent Educ* 2016;80(6):705-20.