Contemporary Concepts in Carious Tissue Removal: A Review

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REVIEW ARTICLE

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Contemporary concepts in carious tissue removal: A review

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Abstract

Objectives: Based on a changed understanding of the disease caries and its pathogenesis, strategies for carious tissue removal have changed, too. This review aims to summarize these changes and to provide clinical recommendations.

Overview: Removing all carious dentin from a cavity is not needed any longer to manage caries or the carious lesion. Instead, the carious lesion should be treated in a way allowing to arrest its activity, while preserving sound tooth tissue and pulp vitality. For teeth with vital pulps, a number of removal strategies have been developed: (1) Nonselective (complete) removal, which is not recommended any longer, (2) Selective removal to firm dentin, where firm dentin is left centrally and hard dentin peripherally, allowing the placement of a long-lasting restoration while avoiding the removal of remineralizable tissue; this is recommended for shallow or moderately deep lesions; (3) Selective removal to soft dentin, where soft or leathery dentin is left in proximity to the pulp and sealed beneath a restoration; this is recommended for deep lesions; (4) Stepwise removal; which combines different strategies and is also suitable for deep lesions, at least in adult patients. Alternatives include not removing but sealing the lesions using resins (for shallow, noncavitated lesions) or stainless steel crowns (the Hall Technique, for cavitated lesions in primary molars), or opening up the lesion and regularly cleaning it (nonrestorative cavity control, currently not supported by sufficient evidence).

Clinical significance

Dentists should tailor their carious tissue removal strategy according to tooth type and, more importantly, lesion depth.

KEYWORDS
dental materials, endo/pulp, operative dentistry

1 | MANAGING CARIES AND CARIOUS LESIONS

Managing caries and carious lesions were the subject of debate of a recent international consensus meeting[1,2] the findings of which have substantially inspired this review. Traditionally, dental caries has been understood as an infectious disease, with carious tissues (mainly bacterially contaminated—"infected"—and demineralized—"affected" dentin) requiring eradication of the causative microorganisms for "curation".[3] In contrast, the contemporary understanding of caries defines it as an ecologic imbalance within the dental biofilm, with acidogenic (acid-producing) and aciduric (acid-withstanding) bacteria being more competitive under frequent intake of carbohydrates (which are metabolized to acids) and eventually dominating the biofilm.[4] The result is a further imbalance between mineral gain (from saliva) and mineral loss (by demineralization), leading to the induction of the symptom of the disease, the carious lesion. Based on this "ecologic plaque hypothesis," the traditional therapy of caries and carious lesions has been questioned. A number of studies found mechanical removal unable to fully eliminate all bacteria from a cavity,[5–8] whilst even if such removal was possible, it would neither "heal" caries nor necessarily facilitate control of the lesion activity. Merely removing carious dentin should thus be regarded as a symptomatic rather than a causal treatment, which is why modern concepts for managing caries and its symptoms (ie, carious lesions) aim to avoid invasive treatments wherever possible and instead attempt to control the activity of the biofilm and the lesion.

For noncavitated lesions, a great many options are available to allow such management (activity control) without any removal of tissue.[9] For example, noninvasive strategies limit the intake of carbohydrates via dietary control, thus re-balancing the composition and activities of dental biofilms. Biofilm removal or inactivation via mechanical or chemical oral hygiene control similarly target the biofilm, its composition or maturation, and activity. Remineralization strategies employing fluorides, for example, promote remineralization of lesions while decreasing the solubility of dental hard tissues, thus reducing their susceptibility to demineralization. Microinvasive strategies remove only few micrometers of tissue and employ resins to cover (seal) or infiltrate dental tissues (mainly enamel). The applied diffusion barrier impedes acid diffusion into the dental tissues and arrests treated lesions.[10]

None of these strategies remove carious tissues, but aim to rebalance the biofilm activity and/or the equilibrium of mineral loss and mineral gain of dental hard tissues. Such treatments were traditionally restricted to noncavitated (ie, cleansable) lesions, while cavitated (noncleansable) lesions were thought to be in need of a restoration to recreate an intact, cleansable surface. It should be noted that lesions that are not cleansable can be transformed into cleansable lesions (nonrestorative cavity control).[11–13] However, this treatment is not widely established yet, mostly restricted to primary teeth and does not replace restorative management of cavitated lesions.

In summary, the main goal of caries management should be prevention of lesion development. For existing carious lesions, the priority should be to control its activity non- or microinvasively instead of removing and replacing them restoratively, thereby preventing further hard tissue loss and postponing or avoiding the restorative cycle.[14,15] However, these options are usually not available for cavitated (noncleansable) lesions. Here, invasive (restorative) interventions are oftentimes needed.

2 | CARIOUS TISSUE REMOVAL

The mentioned consensus meeting largely focused on terminology and clinical recommendations on carious tissue removal.[1,2] This meeting came to the conclusions that removing carious tissue was traditionally seen as inherent part of any restorative therapy. The traditional aims of such removal were to create a preparation that retains the (traditionally nonbonded) restoration, to remove bacteria, and to remove demineralized dentin.[1,2] Modern restorative materials adhere to the tooth microretentively or chemically, not via macroretention. Based on the described understanding of caries, removing bacteria does not seem a necessity before placing a restoration, as any restoration that seals the preparation deprives remaining bacteria of carbohydrates.[16–20] Also, demineralized dentin can be remineralized[21–23] and does not need to be removed. In summary, none of these traditional aims longer apply. Thus, there is a consensus that the only strong reason for carious tissue removal before placing a restoration is to create a) a sufficiently large surface for bonding and b) a support for the restoration against masticatory forces.[2]

3 | CONCEPTS OF CARIOUS TISSUE REMOVAL

As a further consensus from this meeting, it was decided that—based on the described pathology of dental caries, the threshold and justification for restorative interventions and the aim of carious tissue removal —dentists should (1) retain sound remineralizable dentin or enamel, (2) attempt to hermetically seal any residual carious dentin beneath the restoration by creating a peripheral zone to which a restoration can be sufficiently bonded, (3) maintain pulpal vitality by avoiding pulp exposure and retain as much residual dentin as possible, and (4) maximize restoration longevity by creating surfaces for bonding and support.[1,2]

The risk of pulpal exposure is relevant for teeth with asymptomatic vital pulps with deep carious lesions (radiographically involving the inner pulpal third or quarter of dentin). Avoiding pulp exposure in such teeth allows them to be retained long-term and avoid potentially painful, costly, and invasive endodontic treatments,[24–26] and might be prioritized over restorative success. In contrast, in lesions without risks for the pulp (ie, shallower lesions not extended into the inner third or quarter of the dentin), restoration success might be given higher priority than pulpal health, which is at little risk anyway.[1,2]

There are generally five main strategies how to remove carious tissues. These range from aiming to remove any softened dentin from the cavity to not removing any carious dentin at all. Traditionally, these have been discriminated according to their degree of "completeness" of the excavation process. However, given that regardless of the chosen excavation method and the applied criterion to assess the excavation results, bacteria remain in the cavity, and considering that removing these bacteria should not necessarily be an aim of carious tissue removal, new descriptive names have recently been suggested.[1,27] These names are based on what is done during the excavation process rather than the perceived degree of completeness.[1,2]

The following definitions have been derived by consensus and are cited here[1,2]:

- "Nonselective removal to hard dentine (formerly complete excavation or complete caries removal) uses the same criterion in assessing the end point of carious tissue removal for all parts of the cavity (ie, peripherally and pulpally). Only hard dentine is left so that demineralized dentine "free" of bacteria is completely removed. This is considered overtreatment and no longer advocated."
- "Selective removal to firm dentine leaves "leathery" dentine pulpally; there is a feeling of resistance to a hand excavator while the cavity margins (ie, peripheral dentine) are left hard (scratchy) after removal. Selective removal to firm dentine is the treatment of choice for both dentitions—in shallow or moderately deep cavitated dentinal lesions (ie, lesions radiographically extending less than the pulpal third or quarter of dentine). In deeper lesions, selective removal to firm dentine bears significant risks for the pulp, which is why other strategies should be considered."

- "Selective removal to soft dentine is recommended in deep cavitated lesions (ie, extending into the pulpal third or quarter of the dentine). Soft carious tissue is left over the pulp to avoid exposure and "stress" to the pulp, thereby promoting pulpal health, while peripheral enamel and dentine are prepared to hard dentine, to allow a tight seal and placement of a durable restoration. Selective removal to soft dentine reduces the risk of pulpal exposure significantly as compared with nonselective removal to hard or selective removal to firm dentine."

- "Stepwise removal is carious tissue removal in two stages, ie, visits:[18,28–30] Soft carious tissue is left close to the pulp in the first step, while in the periphery only hard dentin is left." A temporary restoration is placed and the patient returns after 6–12 months. When re-entering, carious tissue removal is continued until firm dentin remains close to the pulp. As the second step bears additional risks of pulpal exposure compared with Selective Removal to Soft Dentin,[30–32] generates treatments costs, and is again burdening the patient, there is increasing debate regarding the continued use of Stepwise Removal. Especially in primary teeth, Selective Removal to Soft Dentin might be preferable.
- A last strategy is not removing any carious tissue at all. This will be discussed below.

The first four strategies have been evaluated by several randomized trials, which were reviewed and meta-analyzed.[30,33] The risk of pulpal exposure was significantly reduced when selective to soft dentin or stepwise instead of selective to firm dentin or nonselective excavation was performed (odds ratio [95% confidence interval]: 0.31 [0.19/0.49]). Not attempting to remove all bacteria or demineralized dentin in proximity to the pulp led to a risk reduction of 70% for pulp exposure.[33] The evidence supporting this reduction was graded as moderate, ie, the second-best rating according to the GRADE group (⊕⊕⊕⊖). This risk is decreased even further if only Selective Removal to Soft Dentin (and not Stepwise Removal) is compared with Selective Removal to Firm. If these data are extrapolated into a long-term perspective, for example, using simulation studies, the importance of preserving pulpal integrity and vitality becomes clear. Less invasive excavation retains teeth significantly longer and avoids endodontic treatments, thereby reducing treatment costs dramatically (up to 50%).[24]

If teeth with pulp exposure are excluded for further analyses, there are further implications of different removal strategies: The risk of pulpal complications (hypersensitivity, loss of vitality, abscess) decrease when using Selective to Soft or Stepwise instead of Selective to Firm or Non-Selective Removal (OR: 0.58 [0.31/1.10]), a finding graded as being supported by weak evidence (⊕⊕⊖⊖). Finally, restorative and other nonpulpal risks were assessed, and found to not significantly differ between differently excavated teeth. However, leaving large amounts of carious dentin might well be detrimentally to restoration success,[34] as will be discussed now.

- As discussed, the fifth strategy is not removing any carious tissue at all. There are two main interventions in this category; sealing carious tissue and opening up carious lesions and managing them nonrestoratively (as discussed, NRCT). Sealing can be performed using resin sealants. This strategy is highly efficacious for arresting noncavitated lesions, and might also be suitable for managing minimally cavitated lesions in nonloaded areas (buccally on molars, eg). The carious tissue is not removed at all; in some circumstances, the enamel margins are cleaned and beveled ("ultraconservative removal") and the sealant is then applied. In any case, resin sealants are not sufficiently stable for high masticatory loads being placed on them when they are not supported by sound tooth tissue, which is why this sealant strategy is limited in its indication.[34–37] A second sealant strategy is the placement of stainless steel crowns on primary molars with cavitated carious lesions. This is called the Hall Technique.[38,39] This technique is supported by clinical studies and seems capable of overcoming the challenges of preserving pulp vitality during carious tissue removal in primary molars (given their anatomy, pulp exposure is highly likely here) and of restoring these cavities in primary teeth (where most conventional restorations, for example based on composites, compomers, or glass ionomer cements, perform rather poorly compared with permanent teeth).[40–42] The second strategy, NRCT, is also limited to primary teeth, but has not been found to be effective when compared to alternatives.[43] This might be, as it is demanding a lot from patients/parents, and dentists: In NRCT, cavitated carious lesions are opened up by removing overhanging enamel and dentin using burs or chisels, and then the cavity needs to be cleaned and fluoridated regularly. The latter is something which is hard to maintain in patients which have not shown the capacity to perform an effective oral hygiene in the past.

4 | RESTORATIVE ISSUES AND OPEN QUESTIONS

One focus of research in cariology is currently the restorative impact of leaving carious dentin beneath restorations. The background of carious dentin destabilizing restorations were reduced bond strengths of conventional (etch-and-rinse) adhesives to demineralized (affected) and bacterially-contaminated, degraded (infected) dentin,[44] as well as a reduced fracture resistance of "incompletely" compared with "completely" excavated teeth.[45] Demineralized dentin is more porous, with tubular obliterations, impeding full penetration of the exposed collagen with primer/adhesive materials and leading to a thicker, incompletely penetrated hybrid layer.[46] In addition, carious dentin is softer, and feared to provide insufficient mechanical support for the placed restoration, especially against occlusal masticatory forces.[47] The combination of reduced bond strengths plus lacking support was thought to compromise restoration stability, leading to reduced margin integrity and increased risk of secondary caries as well as higher risk of restoration fractures.

However, several *in vitro* studies did not confirm such increased risks for fracture resistance[48] or marginal integrity and secondary caries susceptibility.[49] The possible reason why one study found the fracture resistance to be decreased if carious dentin was left beneath a restoration and others did not, was the location of the lesion. For occlusal lesions, masticatory forces are directed onto the softer, less elastic dentin, leading to the restoration fracturing into the lesion.[45] For proximal, pulpoaxially located lesions, occlusal forces are directed in parallel along the lesion, reducing the mechanical impact of carious dentin on the restoration stability. It should be noted that these speculations have not been substantiated so far. *In silico* analysis, for example, using finite element analysis, might be used to elucidate this further. A recent study in this direction, for example, found selective removal or sealing (ultraconservative removal) to have mechanical benefits over nonselective removal in shallow cavities.[50]

Further research also did not find significant differences between adhesive system performance in selectively and completely excavated teeth. Dentists might therefore continue to use their "standard" adhesive system regardless of the performed carious tissue removal strategy. For restoring teeth with deep lesions, it might be pragmatic to use a self-etch adhesive system after selectively conditioning the enamel using phosphoric acid. Similarly, it remains unclear if one should use specific restoration materials for extended cavities resulting from selective removal. A recent *in vitro* study reported a possible advantage of using fiber-enforced composite systems, as these might reinforce the tooth and thus increase its fracture resistance.[51]

Besides *in vitro* data, a great number of clinical studies evaluated teeth after Selective Removal to Soft Dentin. These were summarized recently, building on data from over 2800 teeth which had been followed over a median period of 16 months.[31] The median annual failure rate of these teeth—most of them with lesions reaching the inner dentin half or even third/quarter (ie, advanced or deep lesions)—was 4%. Compared with recently reported annual failure rates of teeth with deep lesions which received conventional therapy in general practice (in mean 5.6%),[41] Selective Removal to Soft Dentin reduces risk of failure, as expected based on randomized trials. In summary, restorative complications do not seem to be greatly increased if less invasive removal strategies are performed.

However, clinical data also indicate that not removing any carious tissue from cavitated lesions in posterior teeth is problematic: As discussed, carious dentin has inferior mechanical properties compared to sound dentin. The few studies available show higher risks of mechanical failure in teeth where only sealants where placed over these cavitated lesions.[35,36] If this strategy is chosen, and (minimally) cavitated lesions are sealed without any excavation, it is highly relevant to monitor the lesions in short intervals. In this case, resealing might be easily possible without significant lesion progression in case the sealant fractures or is lost. If, however, this is not noticed in time, progression is likely, with subsequent risks for the pulp.

There are additional uncertainties. Cavity lining has been recommended for deep cavities for decades, while clinical evidence finds the most commonly used cavity liner, calcium hydroxide, to have only limited antibacterial effects compared with other materials,[52] and to increase rather than decrease clinical risk of failure.[53,54] This might be due to the liner destabilizing the restoration while adding only very limited benefit. Alternative lining materials based on calcium silicates might be an alternative here.

Matrix metalloproteinases (MMPs) activity is greater in carious dentin than in sound dentin, which might lead to long-term leakage of restorations due to degradation of the hybrid layer (which, as discussed, often contains incompletely resin-impregnated collagen fibers when bonding to carious dentin is performed). Ethanol pretreatment and the subsequent use of hydrophobic bonding systems have been proposed as one way to overcome this issue, as MMPs are active only under the presence of water. Similarly, MMP inhibition via chlorhexidine (applied, eg, as part of re-wetting the cavity when using etch-and-rinse adhesives) or specific components of bonding systems have been suggested. None of these techniques have, so far, been convincingly shown to yield better clinical outcomes, though, than performing the bonding conventionally (without MMP inhibition). In the future, long-term data (5–10 years) from randomized controlled trials might be able to demonstrate the advantages of MMP inhibition on restoration survival.[55]

Sealed carious lesions remain visible on radiographs due to their radiolucency, which might lead to false-positive diagnoses and unnecessary re-treatments. Tagging of lesions with a radiopaque material prior to restoring the cavity has been suggested to overcome this problem, and seems suitable to distinguish active from arrested sealed lesions as well.[56] Such treatment, for example, using stannous chloride, also has significant antibacterial effects. However, it also decreases bond strengths when the radiopaque substance is applied in high concentrations. Moreover, the clinical applicability has also not been evaluated to date.[57]

5 | CONCLUSIONS

Growing evidence indicates that less invasive strategies are effective for managing carious lesions. Nevertheless, for cavitated lesions, restorative interventions are oftentimes required. Prior to restoration placement, carious tissue removal (excavation) is usually performed. However, traditional reasons for the necessity of such excavation mostly no longer apply; the only strong reason for removing carious dentin is to allow subsequent placement of a long-lasting restoration. Thus, carious tissue removal should be guided by how to improve treatment outcomes, not by the perceived degree of "completeness." Important guiding principles are to preserve pulp vitality, seal the cavity, and maximize restoration success. Thus, in shallow or moderately deep lesions, there is no strong argument against removing all carious tissues in the periphery and excavating until firm dentin remains in proximity to the pulp. For deep lesions (in risk of pulp exposure), the periphery should be excavated similarly, whilst for pulpal areas, soft dentin might be left to avoid exposure. Such excavation has been found to prevent pulpal complications and be more effective and less costly long-term. Both *in vitro* and clinical data confirm the suitability of these approaches also with regards to restorative success, while uncertainty remains with regards to cavity lining, adhesive strategies and the radiopacity of the sealed lesions. Dentists are encouraged to choose their carious tissue removal strategies according to the tooth type and lesion depth.

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CONFLICT OF INTEREST

The author does not have any financial interest in any of the companies whose products are included in this article.

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