Secondary Caries and Microleakage

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Secondary caries – questions

1. How to best predict secondary caries?
2. How to best prevent secondary caries?
3. How to best identify secondary caries (early)?
4. How to best manage secondary caries?

Etiopathogenesis of secondary caries – 1/3

Bulk fracture → caries OR Caries → bulk fracture?

Secondary caries – questions

The answers will undoubtedly be influenced by the stakeholders’ understanding of etiopathogenesis

1. How to best predict secondary caries?
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3. How to best identify secondary caries (early)?
4. How to best manage secondary caries?
Secondary caries – questions

The answers will undoubtedly be influenced by the stakeholders’ understanding of etiopathogenesis.

1. How to best predict secondary caries?
   - Understanding of etiopathogenesis + Diagnostic test validity and reliability

2. How to best prevent secondary caries?
   - Material – operator – patient factors

3. How to best identify secondary caries (early)?
   - Understanding of etiopathogenesis + Diagnostic test validity and reliability

4. How to best manage secondary caries?
   - Understanding of etiopathogenesis + Effectiveness of interventions

Desire to avoid adverse clinical outcomes by the development of (minimum) specifications for dental materials

Specifications according to tests – which ones predict adverse clinical outcomes?

**Static tests?**
- Compressive (crushing) strength, e.g., 1h. & 24 h.
- Tensile strength, e.g., 5 min.
- Transverse strength, e.g., 1h. & 24 h.
- Modulus of elasticity (Young's Modulus)
- Shear modulus

**Dynamic tests?**
- Compressive modulus
- Tensile modulus
- Bending modulus
- Resilience
- Fatigue
- Fracture toughness

Validation of a test
- Reproducible
- Known parameters
- Low C.V. (#samples)
- Calibrated devices

Other defined tests?
- Flow (Creep), 3-24 h.
- Dimensional change, e.g., 5 min. - 24 h.
- Polymerization-/Setting—contraction/expansion
- Hardness
- Thermal expansion coefficient
- Water solubility / - sorption
- Abrasion resistance (Wear)
- Adhesion
- Surface roughness
- Marginal leakage
- «Retention strength»
- Color stability

**Other undefined tests?**

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**Other undefined tests?**
- Abrasion resistance (Wear)
- Adhesion
- Surface roughness
- Marginal leakage
- «Retention strength»

“Neither dentists nor laboratory researchers have a clue as to what these tests say on possible clinical outcome in terms of predictability and longevity”


Restoration material and adverse outcome

undesirable performance

- Degradation
  - Bulk (/surface)
  - Interface (/margin)
- Material loss
- Fractures/cracks
- Rough surface
- Poor adaptation to tooth tissues
- Discoloration
  - Surface (/bulk)
  - Margin (/interface)

What are the predictors?

Desire to avoid adverse clinical outcomes by the development of standards for clinical practice and research


ADA

- 1972: ADA Recommended standard practices for clinical evaluation of dental materials and devices
- 1973: ADA Guidelines for reporting clinical trials
- 1977: California Dental Association "CDA system"

Evidence that specifications according to tests predict adverse clinical outcomes?

Weak - according to current leading content experts, although perhaps substantially inferior products may be identified

Restoration material and adverse outcome

undesirable performance versus risk factor for:

- Degradation
  - Bulk (/surface)
  - Interface (/margin)
- Material loss
- Fractures/cracks
- Rough surface
- Poor adaptation to tooth tissues
- Discoloration
  - Surface (/bulk)
  - Margin (/interface)

What are the predictors?

Why and how much are the risks inflated?

Desire to avoid adverse clinical outcomes by the development of standards for clinical practice and research


ADA

- 1981: Expansion of the ADA acceptance program: Composite resin materials for occlusal class I and II restorations
- 1989: Composite resins for posterior restorations (r1996, 2001)

1977: Recommended format. Clinical comparison of several anterior and posterior materials
1982: Recommendations for clinical research protocols for dental materials
1990: Good manufacturing practices, including quality assurance for dental materials
Desire to avoid adverse clinical outcomes by the development of standards for clinical practice and research.

2007: Hickel ea. Recommendations for conducting controlled clinical studies of dental restorative materials & criteria for evaluation of direct and indirect restorations including onlays and partial crowns.


Topics discussed in this presentation
- Dental caries, a brief review
- Restorative materials and the tooth-restoration interface
- The (cavity) "wall lesion" – what is in a word?
- Etiopathogenesis of secondary caries gained from in vitro research
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  - Artificial caries-like lesions adjacent to restorations
  - Secondary caries incidence in controlled clinical studies versus cross-sectional examinations

DENTAL CARIES, A BRIEF REVIEW

Dental caries, a brief review

Dental caries is a dynamic biological process that involves various factors such as microorganisms, host factors, and environmental factors. The process begins with the attachment of bacteria to the tooth surface, followed by the production of acids that cause enamel demineralization. Enamel demineralization leads to the formation of a white or brown lesion, which can progress to a cavity if not treated promptly.

WHAT IS DENTAL CARIES?

Enamel demineralization (Microscopically)
1. Surface zone
2. Lesion body zone
3. Dark zone
4. Translucent zone

Histologic caries

Infective caries
Infected dentin
Radiographic caries

Enamel demineralization may be manifested in dental hard tissues by:
1. Demineralization
2. White or brown (spot) lesion
3. Cavity ("cavitation"")

Cavitation is caused by the formation of cavities, which are localized areas of enamel and dentin that are present in the tooth structure.

Dental caries can be classified into three types:

- Active caries: The carious process is ongoing.
- Arrested caries: The carious process has stopped, and remineralization has occurred.
- Inactive caries: The carious process has stopped, and remineralization has not occurred.

Cavitation is a localized area of enamel and dentin that is present in the tooth structure.

Cavitation is caused by the formation of cavities, which are localized areas of enamel and dentin that are present in the tooth structure.

Dentin sclerotization

Cellular changes in the pulp

Dentin sclerosis is a process that occurs in the dentin of teeth that have been infected or exposed to bacterial by-products such as acids or enzymes.

Central traversal line

Microradiograph: de Medeiros et al. J Microscopy 2012

Relative pore structure of the 4 caries lesion zones

Relative concentrations of important ions. Selective loss of Mg and carbonate is illustrated together with concentration gradients of fluoride and protons from surface to interior.

Variability

Discrimination threshold in dental tissues, resolution, time, costs & complexity

Histopathology of enamel caries

Changes within the zones of a caries lesion

Relative pore structure of the 4 caries lesion zones

Relative concentrations of important ions. Selective loss of Mg and carbonate is illustrated together with concentration gradients of fluoride and protons from surface to interior.

Proposed phase changes in the surface zone and the positively birefringent zone following ingress of protons and fluoride and a net loss of mineral.

Net chemical changes detected at each stage of carious attack.

Diagrammatic representation of changes in enamel mineral crystal morphology within each zone to account for changes in pore structure.

Mineral loss detection methods

Laboratory methods

Destructive methods
- Chemical analysis
- X-sectional microhardness
- Optical microscopy (Polarized light)
- Confocal light microscopy
- Laser scanning microscopy (CLSM)
- Transverse microangiography (TMG)
- Microprobe analysis
- Energy-dispersive spectroscopy (SEM-EDX)
- Raman spectroscopy, and Fourier-transform infrared spectroscopy (FTIR)

Intraoral methods
- Light-, infrared- or laser-induced fluorescence
- Electrical conductivity
- Computerized radiography algorithms for automated detection of lesions
- Optical coherence tomography (OCT)
- Polarization-sensitive OCT (PS-OCT) in combination with near-infrared light

Non-destructive sequential methods
- Surface microhardness
- Iodine absorptiometry / penetration
- Longitudinal MR(LMR)
- Light scattering
- Wave-length-independent MR (WLM,T-MR)
- Microprobe analysis

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Variability

Discrimination threshold in dental tissues, resolution, time, costs & complexity
Creating caries-like lesions artificially in vitro

- Human and non-human, mainly bovine, teeth or tooth specimens
- Several approaches, some specifically tailored to create lesions in enamel or in dentin or in root cement.
- Two methods prevail,(1) an acidified medium without buffering & without pH-cycling; (2) an acidified broth containing usually some strain of Streptococcus mutans
- Mineral loss profiles of the surface and subsurface zones differ with method
- Differences can be large, e.g., at pH=5, a carboxymethyl cellulose gel (6%) causes ~33 volume % mineral loss in enamel per day, while an unstirred solution causes 13% & 26% volume % mineral loss in enamel per hour (with & without added fluorides respectively).
- The ultimate hope is to build the artificial mouth, or at least a steady state microcosm. In spite of some elaborate contraptions we have not succeeded yet to simulate the complexities of the intraoral ecology and microenvironment.

Creating caries-like lesions artificially in situ

- Since early 90’s. Used for multiple research objectives, e.g., assessing erosive or cariogenic potential of various substances, or, appraising the potential for remineralization following application of various oral care products on preconditioned specimens
- Human and non-human specimens
- Specimens mounted in a dental device worn by subjects for various periods
- Surface of the specimens often covered or machined to increase plaque retention
- Demineralization/erosion accelerated by repeat bathing of the device, e.g., caries, 4-8x / day in a 20% sucrose solution
- Demineralization differs from in vitro setups

Are there any differences?

Artificial caries-like lesion versus Artificial caries lesion versus Clinical caries lesion

How is the disease entitled «Dental caries» defined by laypersons, basic scientists, dentists, clinical researchers and epidemiologists?

What is dental caries?

- Dental caries, a brief review
- Restorative materials and the tooth-restoration interface
- The (cavity) "wall lesion" – what is in a word?
- Etiopathogenesis of secondary caries gained from in vitro research
- Microleakage
- Artificial caries-like lesions adjacent to restorations
- Secondary caries incidence in controlled clinical studies versus cross-sectional examinations
The origin of the term «cavity wall lesion»

Hals & Nernæs, Caries Res 1971

Amalgam (in vitro, 1971)
Amalgam (in vivo/vitro, 1975)
Resin composite (in vitro, 1976)

M&M: Polarized light microscopy x60 & Quinoline imbibition

Cavity wall lesion: "tending to encompass filling...", usually without penetrating deeply into the tissue

The depiction of the «wall lesion» originally

A tentative explanation for a radiopaque layer of the cavity wall

From: *Hals & Nernæs, Caries Res 1971

The original and the modified «wall lesion»

Depictions of a radiopaque layer of the cavity wall in original publications

From: Hals & Nernæs 1971
Hals & Halse 1975
Hals & Laegreid 1976

Kidd, Dental Update 1981
Kidd, Quintessence Publ., Co. 1989

The end of the faith in «wall lesions»

2003
2008
2015

An etiopathogenetic theory which persisted for a decade before a "correction" was made in a 2003 cariology textbook

(pp. 272):
- gaps will facilitate pathways for microorganisms, but this does not mean that these cause a caries reaction deep within the gaps. «...» was once believed.
- It should also be kept in mind that these are not empty spaces. They will be filled with proteinaceous material from dentin, liquid and saliva.

The re-emergence of use of the term «wall lesion» in laboratory experiments

The extent of demineralization as an effect of the distance between a specimen and a block of material placed in an acidified medium

Derand et al. Swed Dent J 1991
Nassar & Gonzalez-Cabezas Caries Res 2011

The re-emergence of use of the term «wall lesion» in in situ experiments

Montagner et al. J Dent 2015
Van de Sande et al. J Dent 2014

Specimen size: 1.5x2x1mm
What is dental caries?

The risk of misunderstanding when a poor choice of the term «wall lesion» is combined with an essentialistic perspective on caries.

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Examples of variables in microleakage experiments

- Adhesive brand
- Thick flowable liner
- More microleakage
- Less microleakage
- Corroborate
- Conflicting results

Microleakage observations versus clinical observations

<table>
<thead>
<tr>
<th>Microleakage</th>
<th>Clinical observations</th>
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<td>Less microleakage, Corroborate</td>
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<td>Light cured vs self-cured</td>
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<td>Bonded cavity base</td>
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<td>Thicker flowable flow</td>
<td>Less microleakage in enamel, Corroborate</td>
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<td>Flowable vs. packable resin</td>
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<td>Composite vs. packable resin</td>
<td>Less microleakage in dentin</td>
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</tbody>
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In-vitro caries-like lesions adjacent to restorations – Pioneer studies


In-vitro caries-like lesions adjacent to restorations


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«Lesions» along restorations detected in PLM – what was actually observed?

Hals & Nernaes, 1971:
- Usually a narrow subsurface defect gradually encompassed the whole filling without penetrating deeply into the tissue
- Wall lesions were seen only when imbibed in quinoline and not in air or water only in the PLM

PLM is purely qualitative and does not provide quantitative mineral loss
- Enamel: Quinoline facilitates identification of caries due to pore size selectivity
- Penetration of ions into dental tissues changes optical birefringence, e.g., corrosion products from amalgam such as oxides, sulphides and chlorides of tin, and to a lesser extent zinc and copper
- Dentin: Quinoline binds because of a von Ebener phenol reaction – i.e., a selective binding to collagen, and not due to pore penetration
- Dentin tubules demonstrate form birefringence due to their micrometer size
- Collagen displays form birefringence

Effects of the acidified procedure on the restoration-tooth interface?
- Several strategies - often without consideration of likely negative effects on the restorative material and not occurring in reality intra-oraly
- Restored teeth sometimes exposed directly after the setting time, i.e., not always synonymous with a fully hardened or polymerized material
- In aggressive media crevice corrosion cells are likely generated in the interface along metallic restorations, which lowers the pH further, and cements such as glass ionomers undergo profound surface erosion
- The adoption of methodologies for causing artificial caries-like lesions in enamel were perhaps too uncritically extrapolated to create artificial caries-like lesions adjacent to restorations

More common procedure today: pH cycling: 4.4 → 7 **
** Featherstone et al. 1983/86

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- In aggressive media crevice corrosion cells are likely generated in the interface along metallic restorations, which lowers the pH further, and cements such as glass ionomers undergo profound surface erosion
- The adoption of methodologies for causing artificial caries-like lesions in enamel were perhaps too uncritically extrapolated to create artificial caries-like lesions adjacent to restorations (Featherstone, 1996)
- Dentinal caries is not limited only to demineralization, but becomes heavily infected by mono- or multispecies biofilms, which is difficult to reproduce fully in vitro
- Confounder when the research focus is demineralization-remineralization of artificial caries-like lesions adjacent to restorations made from materials with alleged anticariogenic properties

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The replacement of dental restorations

Primary reason identified in:

Based on compilations of:
- Observational data from:
  - Cross-sectional studies of reasons for replacement of restorations, occasionally with true or estimated time since placement
  - Prospective & retrospective studies of patient cohorts or subgroup analyses of such
  - Experimental studies, with variable internal or external validity reflected by study power, randomization, likelihood of confounding & risk of biases

Which estimates should we trust?

Estimates of incidence & prevalence of secondary caries have ranged from insignificant to extensive. Skepticism has been voiced in both directions
- Potential biases that likely influence estimates is extensive
  - selection bias - performance bias - detection or assessment bias - attrition bias - reporting bias
- Typical examples: patient recruited amongst dental students and faculty; studies not conducted amongst GPs, lack of operational descriptive criteria or judgement of own clinical work; high number of patient dropouts especially amongst the unhappy ones; and the reporting of surrogate outcomes rather than patient-relevant ones
- Results based on clinical work in settings where cost per unit time is of nominal concern do not provide any indications on how the restorative material will perform when placed by the average dentists in mouths of their spectrum of patients during a busy workday.
- The data sampling method, patient demography as well as study methodology influence estimates - Is a quest for “overall” exact values meaningful from a scientific or clinical perspective?

When the «science» in evaluating «scientific research» becomes an exercise in nihilism

- In today’s mobile world, the likelihood of a near-zero attrition is unrealistic.
- At what level does the attrition rate in a dental study become a concern with regard to restoration performance estimates?
- Good research ethics allow study participants at any time to drop out without having to explain why. Coercive offers is generally regarded as unethical.
- Are study participants who return for a follow-up clinical examination many years later in the same clinic representative of the general population when it comes to oral health attitudes and treatment behavior?

What are the alternatives for collecting data?

Health register data, analyzed with Multi-level regression statistics (AKA hierarchical linear r., nested models r., random models r., random parameter models r.)
- UK: Burke & Lucarotti (80K+ adults)
- Finland: Vähänikkilä / Käkilehto /Suni (6K , 36K adults)
- USA: Bogacki / Coppola (300K / 1.500K adults)
- Norway: Dobloug & Grytten (64K adults)
- Brazil: Demarco & Correa (6K adolescents)

Pragmatic (real-life) studies, e.g., in Practice-based Research Networks
- Data on restoration performance obtained in cross-sectional studies reflect the good and the bad operators and oral health attitudes and practices of patients.
- However, how many dentists in real-life
  - prepare textbook-like cavities in teeth to receive the restoration?
  - handle and place restorative materials according to handling instructions?
  - ensure that their patients are motivated and enabled to prevent future caries?

CONCLUSIONS

- It is doubtful whether caries can exist in the restoration-tooth interface independently of an outer enamel caries lesion.
- The term “wall lesion” including its variants is ill defined, has been, and is still being used indiscriminately.
- Stakeholders should avoid using this ambiguous label due to its connotation to an entity that does not exist per se.
Microleakage experiments continue to emerge regardless of multiple reviews questioning the reliability and validity of the method. Several of the approaches used to generate artificial caries-like lesions are very aggressive. Remarkably little discussion has evolved about how these aggressive approaches create microenvironments that do not occur in reality. Corrosion- and biodegradation products may influence the biofilm qualitatively and quantitatively and it is difficult to replicate these variables in any ex vivo environment.

Clinical data sampling method, patient demography as well as study methodology influences the incidence and prevalence estimates of secondary caries. Clinical results based on clinical work in settings where cost per unit time is of nominal concern do not provide any indications on how the restorative material will perform when placed by the average dentists in the mouths of their spectrum of patients during a busy workday.

One of the most gorgeous sites on Maui to watch sunrise & sunset: The Haleakala mountain:

If you plan to see the sunset on top of Haleakala mountain - An important safety message:

SONIC FROM HERTZ WITH A SHORT-CIRCUITED REMOTE CONTROL

AT: 6:18 PM
40 °F

AT: 6.18 PM
40 °F

SONIC FROM HERTZ WITH A SHORT-CIRCUITED REMOTE CONTROL

AT: 6.26 PM
35 °F
What are your options?

1. Panic
2. If you have a satellite telephone:-Call the Hertz emergency centre in Florida and remember how to spell H-a-l-e-a-k-a-l-a before they can help you
3. Start walking down the 10.023 feet mountain in the dark
4. Hijack one of the 4 remaining cars on the parking lot or meet a good Samaritan
5. Remove the battery in your remote controller – (non-validated test)

Thank you for your kind attention