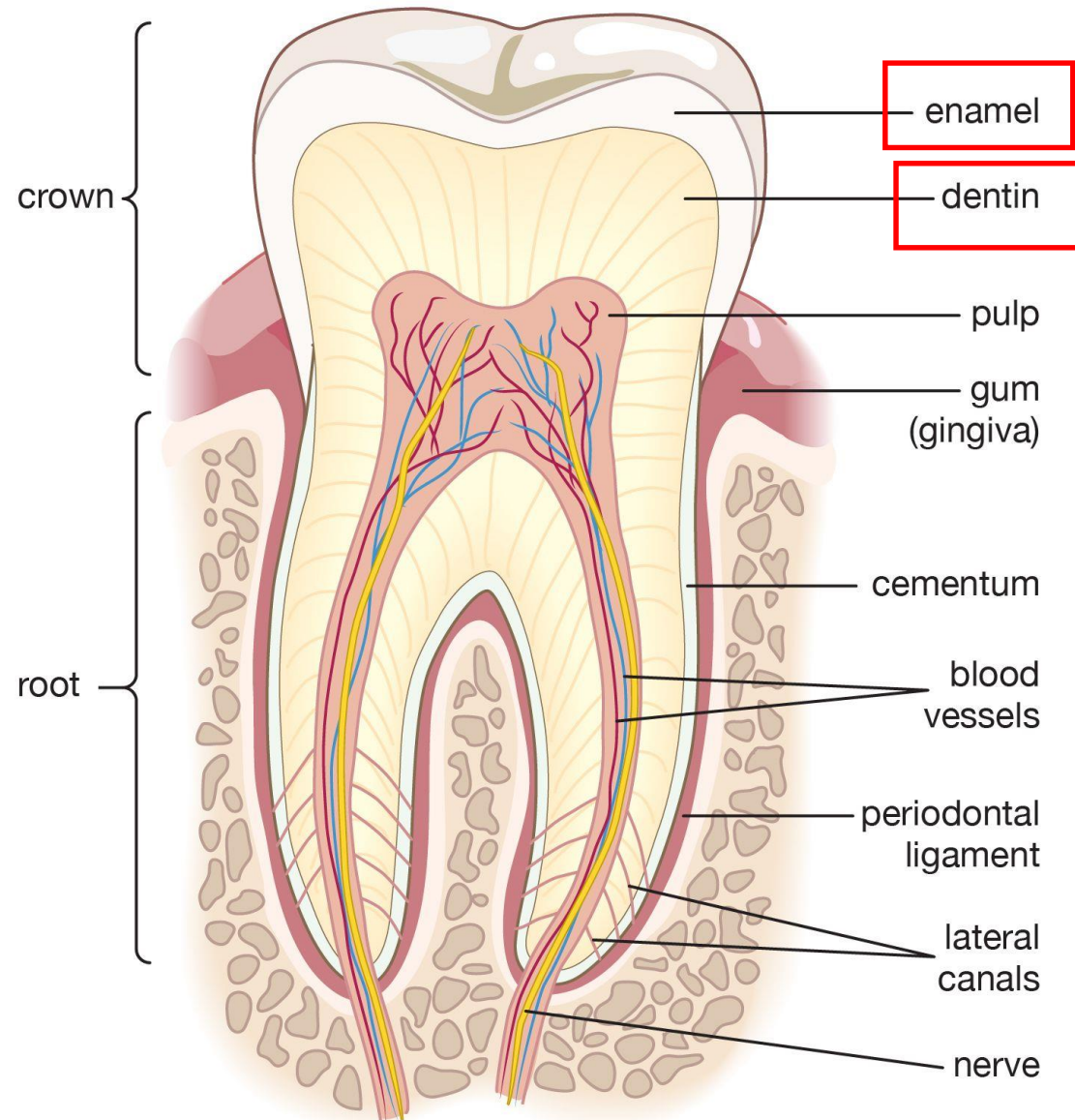


Biophysics in dentistry

Dóra Haluszka

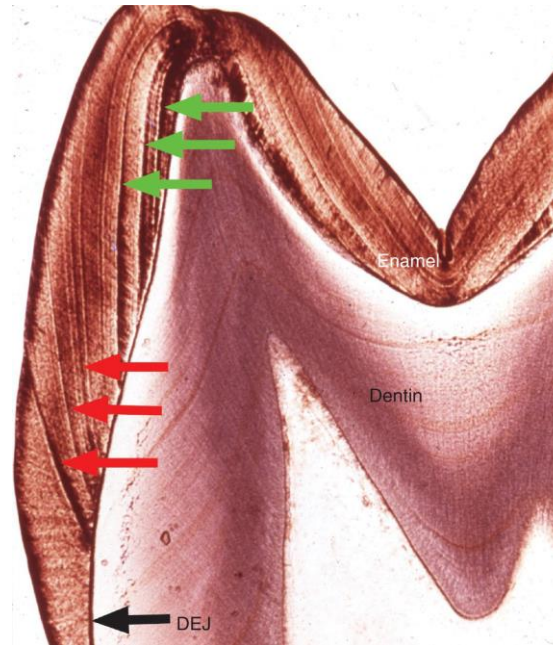
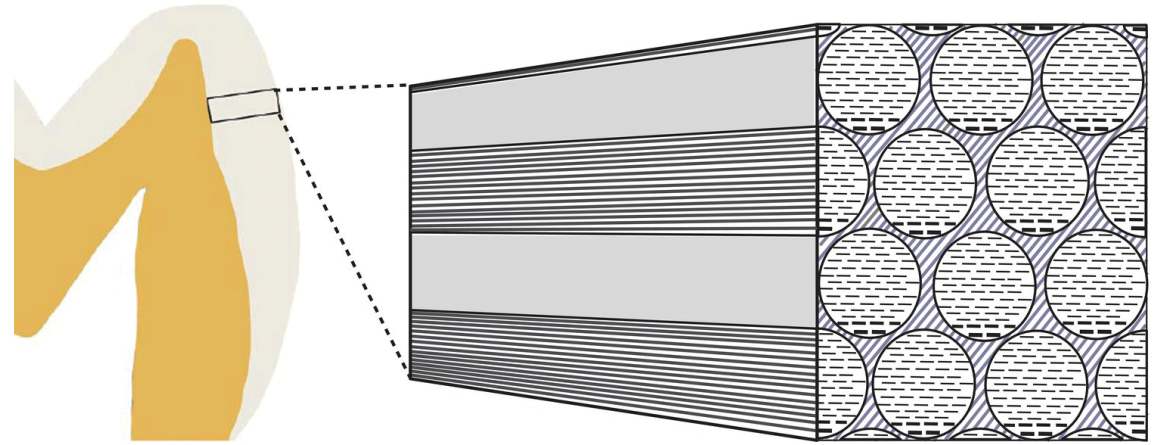
28/02/2025

The structure of tooth

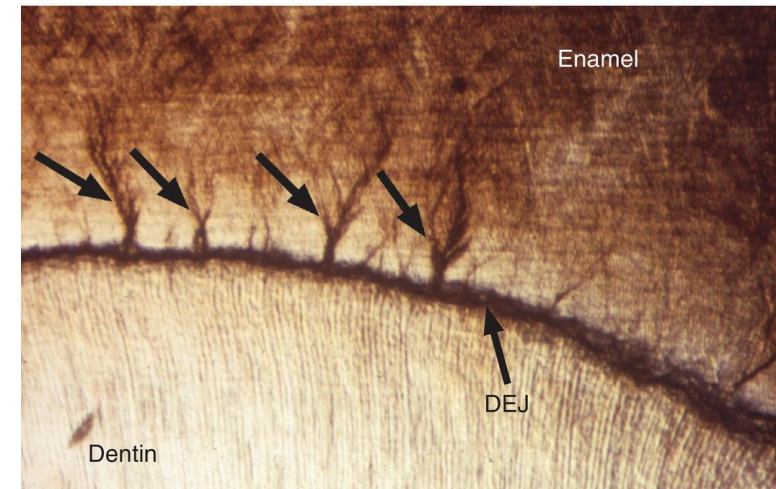


Structure of enamel

- highly mineralized, hardest substance in the human body
- transparent (dentin)
- hydroxyapatite 90%, carbonates, water, organic material
- does not contain collagen
- morphology: ameloblast – enamel rods, enamel prisms
- 4 μm diameter
- the long axis of the enamel rod is perpendicular to the underlying dentin
- acellular, avascular



<https://pocketdentistry.com/4-enamel/#c4-fig-0001>

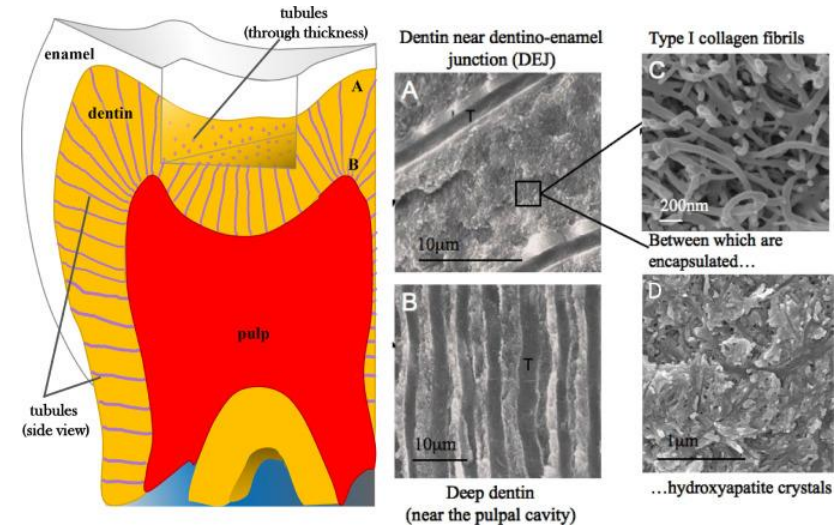


https://pocketdentistry.com/4-enamel/#R_c4-fig-0013

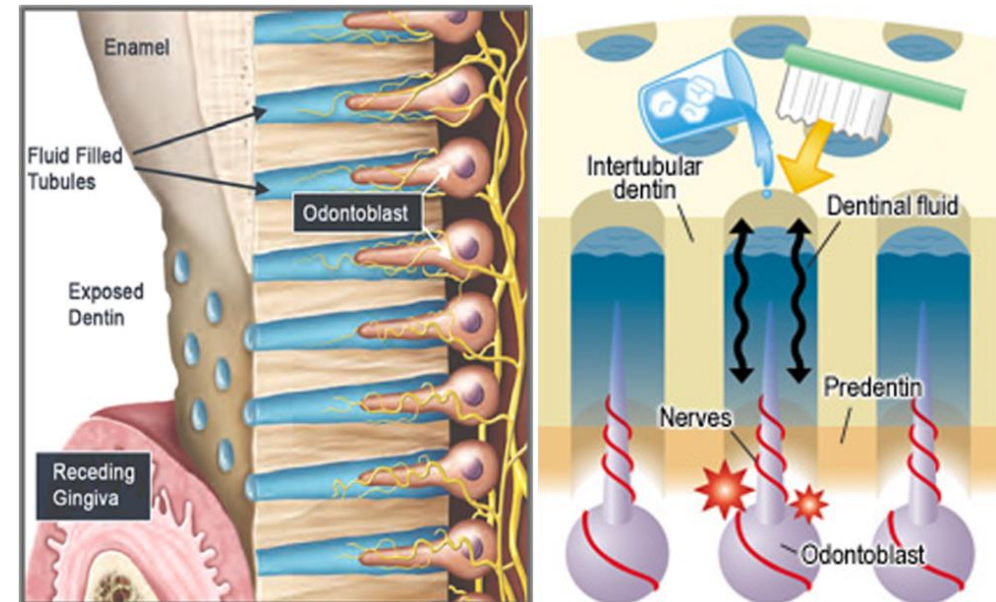
https://pocketdentistry.com/4-enamel/#R_c4-fig-0007

Structure of dentin

- calcified tissue
- 70% minerals, 20% organic material—collagen, 10% water
- does not contain cells
- 3-5 mm thickness
- color of tooth
- types: primary, secondary, and tertiary
- structure: tubules, intertubular dentin, peritubular dentin
- it decays more rapidly
- dentin accumulation in tubules

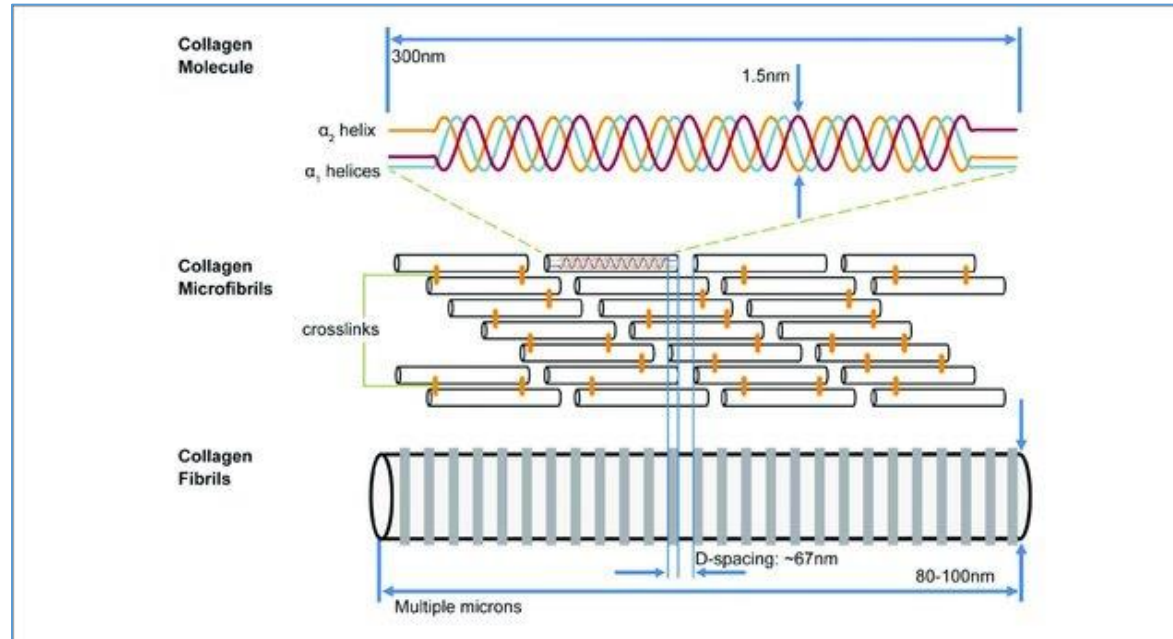


<https://www.sciencedirect.com/science/article/pii/S1359646219305688>

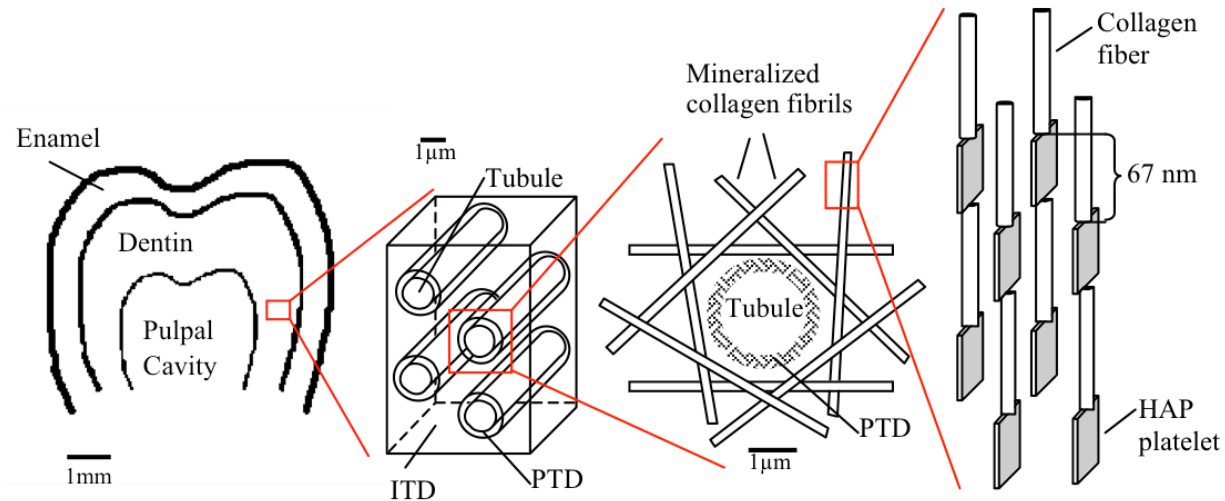


<https://www.dentin.co/new-blog/2017/6/9/dental-hypersensitivity-hydrodynamic-theory>

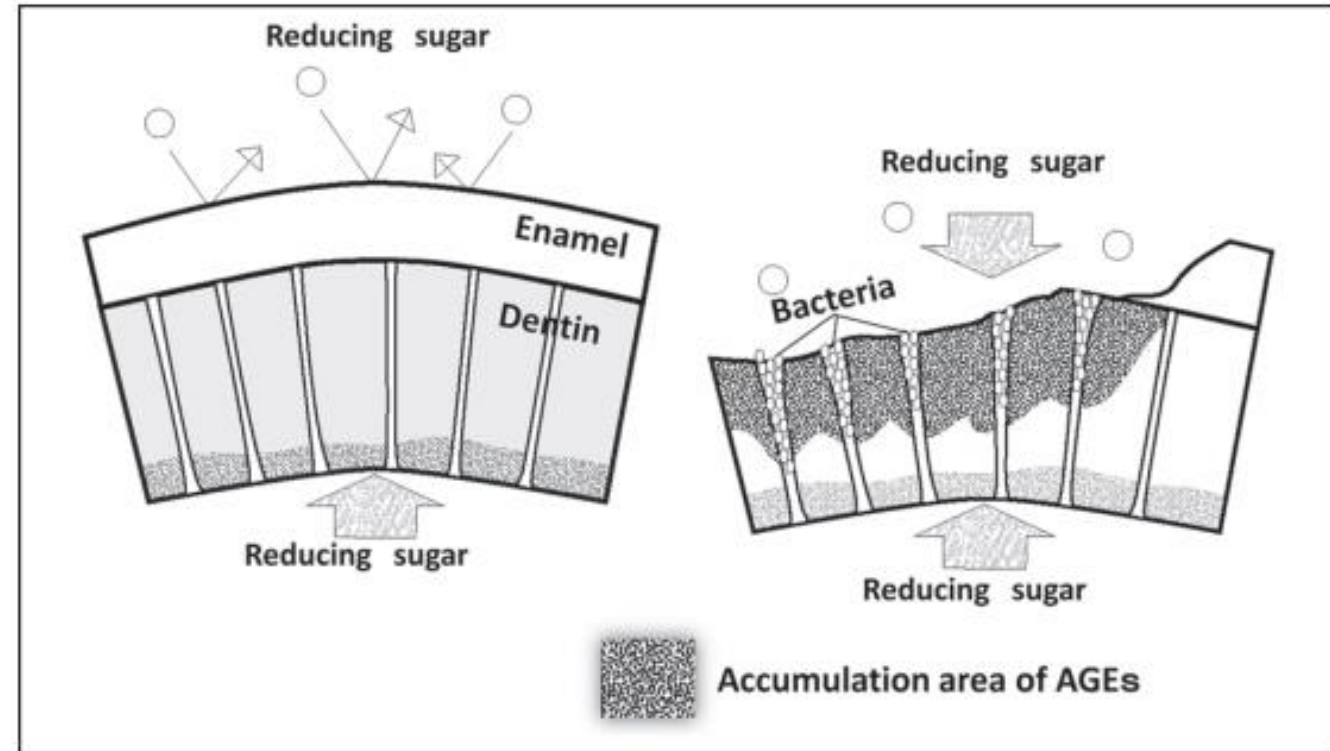
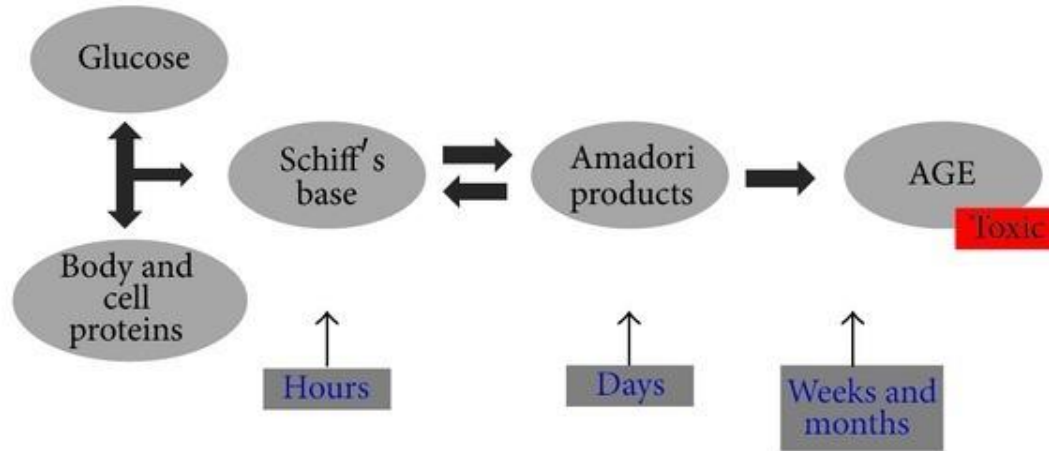
The hierarchical structure of collagen



No turnover!!!



Non-enzymatic glycation of collagen fibers



Matsuda Y, Miura J, Shimizu M, Aoki T, Kubo M, Fukushima S, Hashimoto M, Takeshige F, Araki T. Influence of Nonenzymatic Glycation in Dentinal Collagen on Dental Caries. J Dent Res. 2016 Dec;95(13):1528-1534.

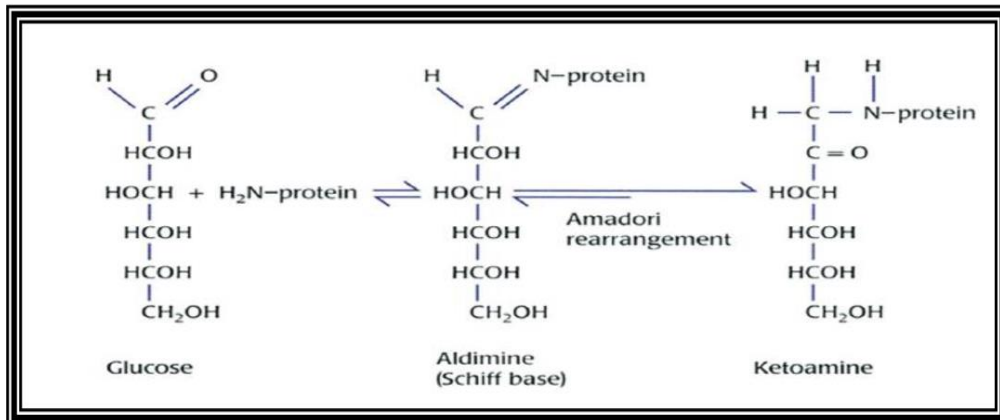
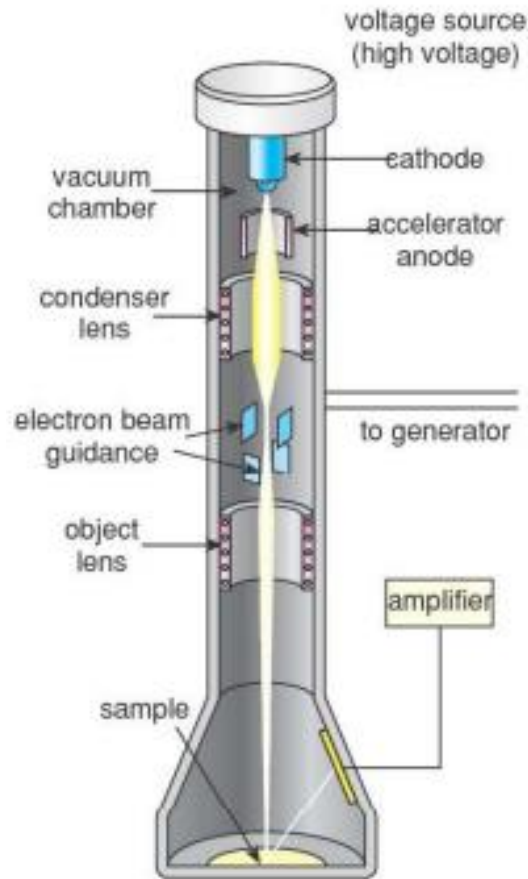


Figure 1: The initial stage of glycation resulting in the formation of a Schiff base and an Amadori product (Voziyan, and Hudson 2005).

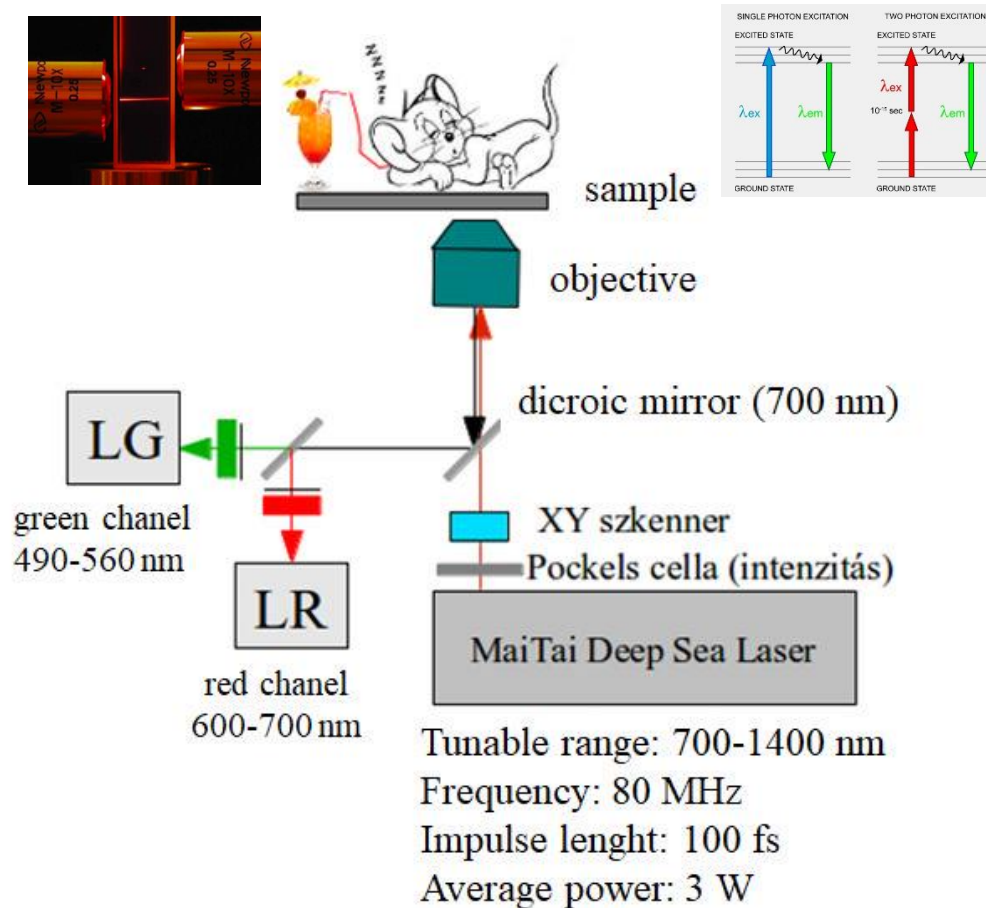
Methods

What techniques can help us answering scientific questions?

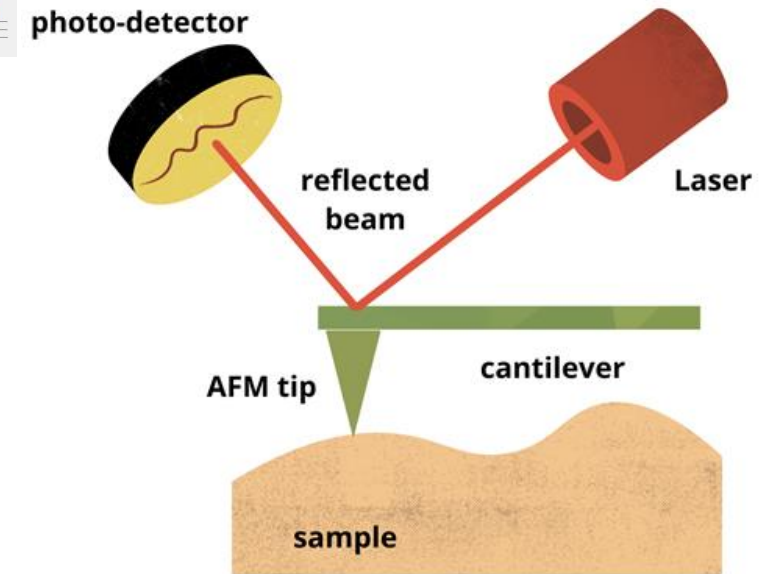
Scanning electron microscopy (SEM)



Two-photon microscopy



Atomic force microscopy (AFM)



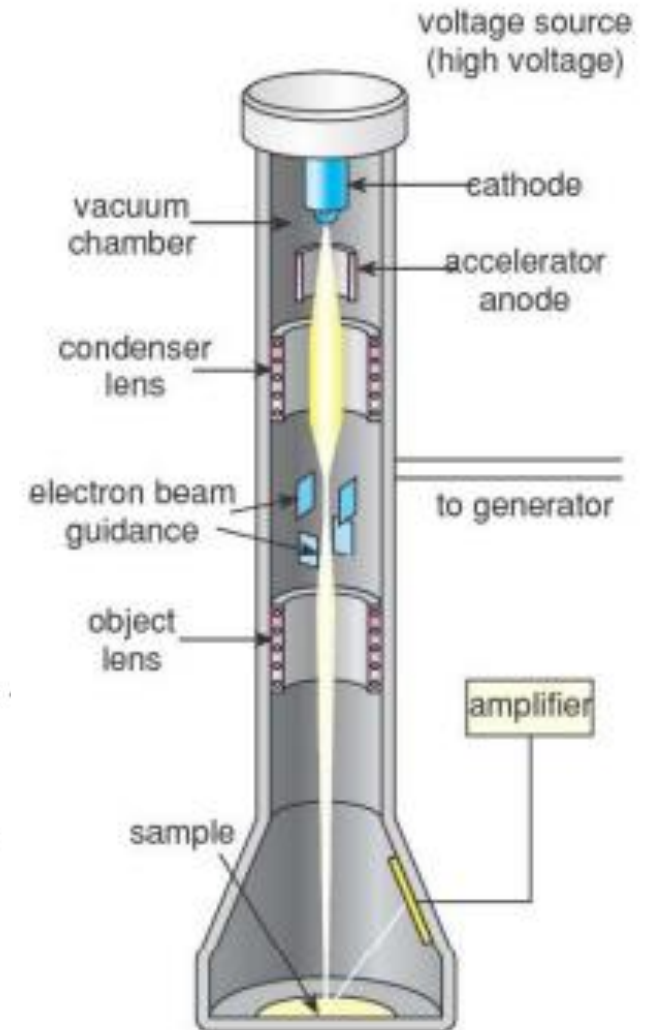
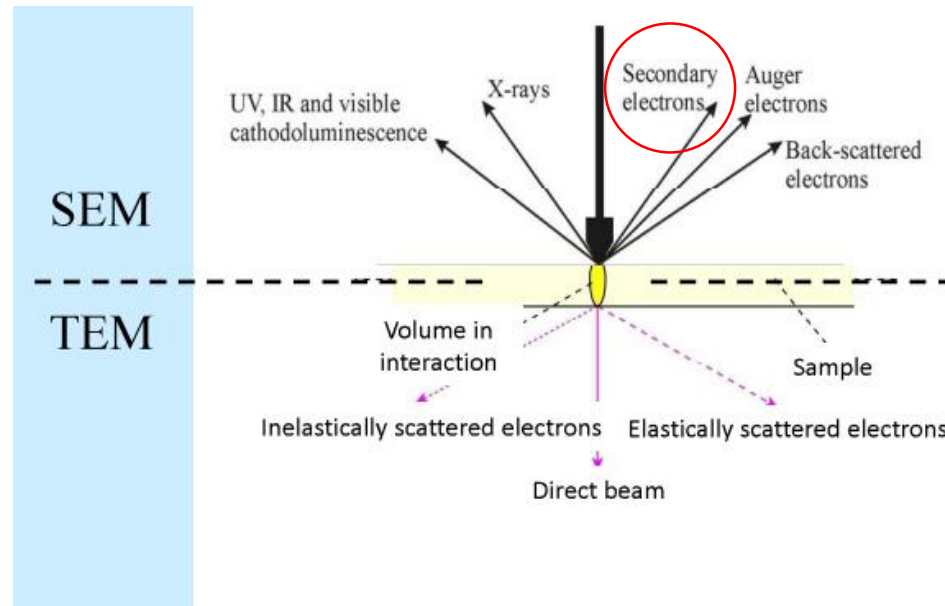
others...

Scanning electron microscopy (SEM)

What can be examined?

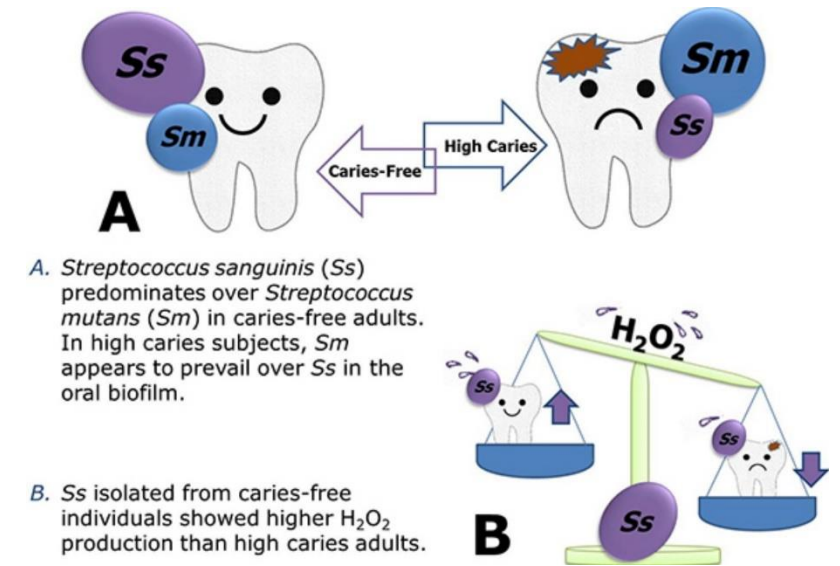
1. Surface structures – plaque formation
2. „Dental wear”
3. Effectiveness of surface treatments

$$\lambda = \frac{h}{mv}$$

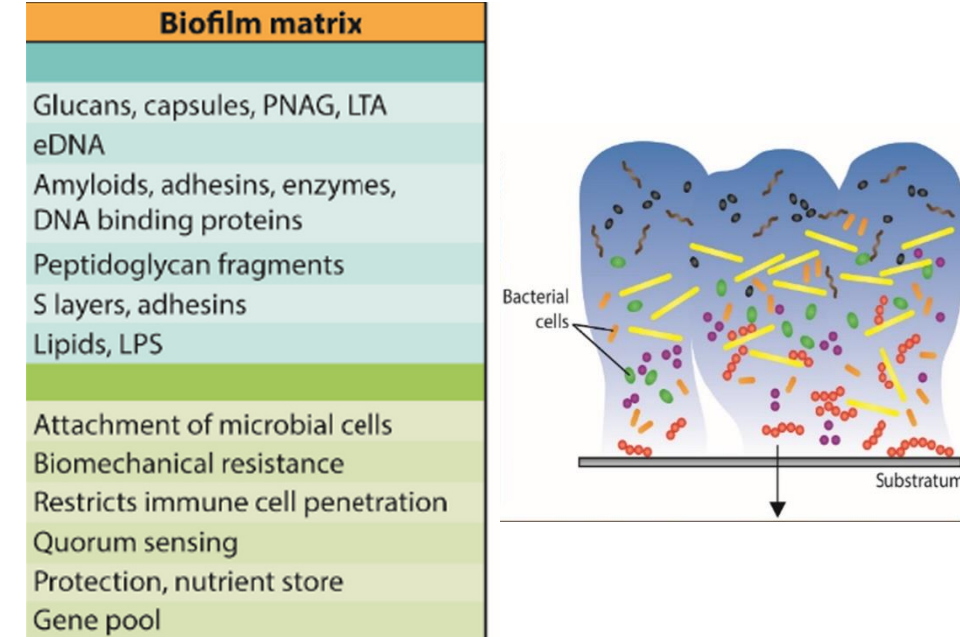


Structure and development of dental plaque

- Biofilm-mediated oral diseases: dental caries, periodontal disease
- Complex communities of microorganisms
- Attached to surface and embedded in extracellular polysaccharides (EPS)
- Attachment of early bacterial colonizer to dental surface: streptococci
- Balance: *Streptococcus sanguinis* vs. *Streptococcus mutans*
- *Streptococcus sanguinis*: commensal species, expresses multiple microbial adhesins
- *Streptococcus mutans*: acidogen strain, increased prevalence within biofilm can lead to progressive demineralization
- Collagen specific surface adhesins – progression of root caries, older people, diabetes



<https://www.sciencedirect.com/science/article/pii/S0003996914002489>

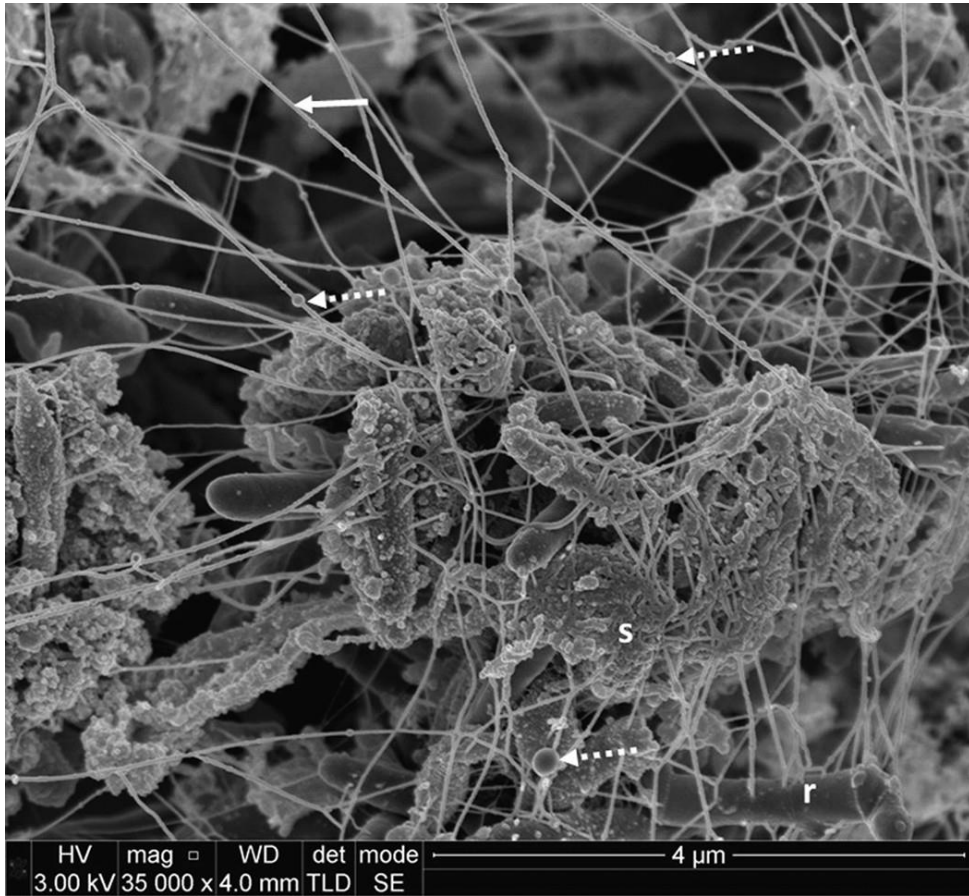


<https://onlinelibrary.wiley.com/doi/full/10.1111/prd.12361>

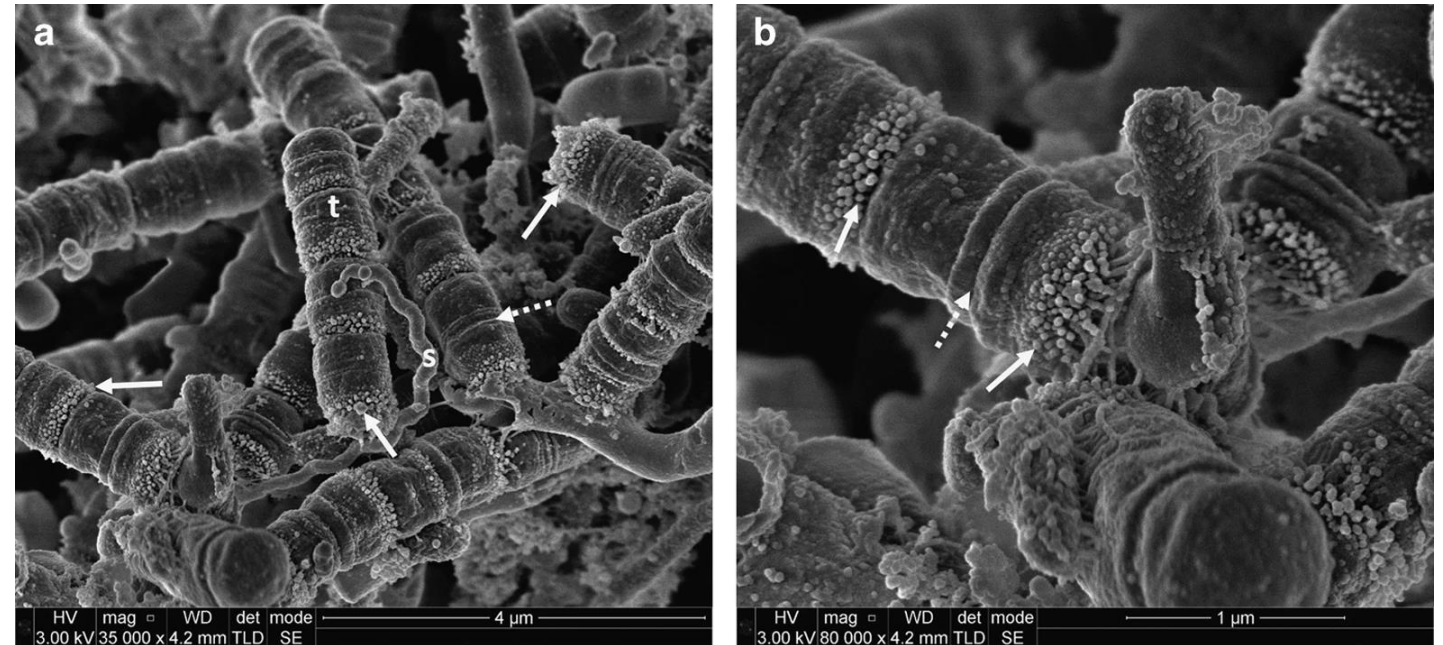
Structure and development of dental plaque

Steps of Plaque Formation	Description
Association	Dental pellicle forms on the tooth (normally on tooth), and provides bacteria surface to attach
Adhesion	Within hours, bacteria loosely binds to the pellicle.
Proliferation	Bacteria spreads throughout the mouth and begins to multiply.
Microcolonies	Microcolonies are formed. Streptococci secrete protective layer (slime layer).
Biofilm formation	Microcolonies form complex groups with metabolic advantages.
Growth or maturation	The biofilm develops a primitive circulatory system

Ultrastructure of dental plaques

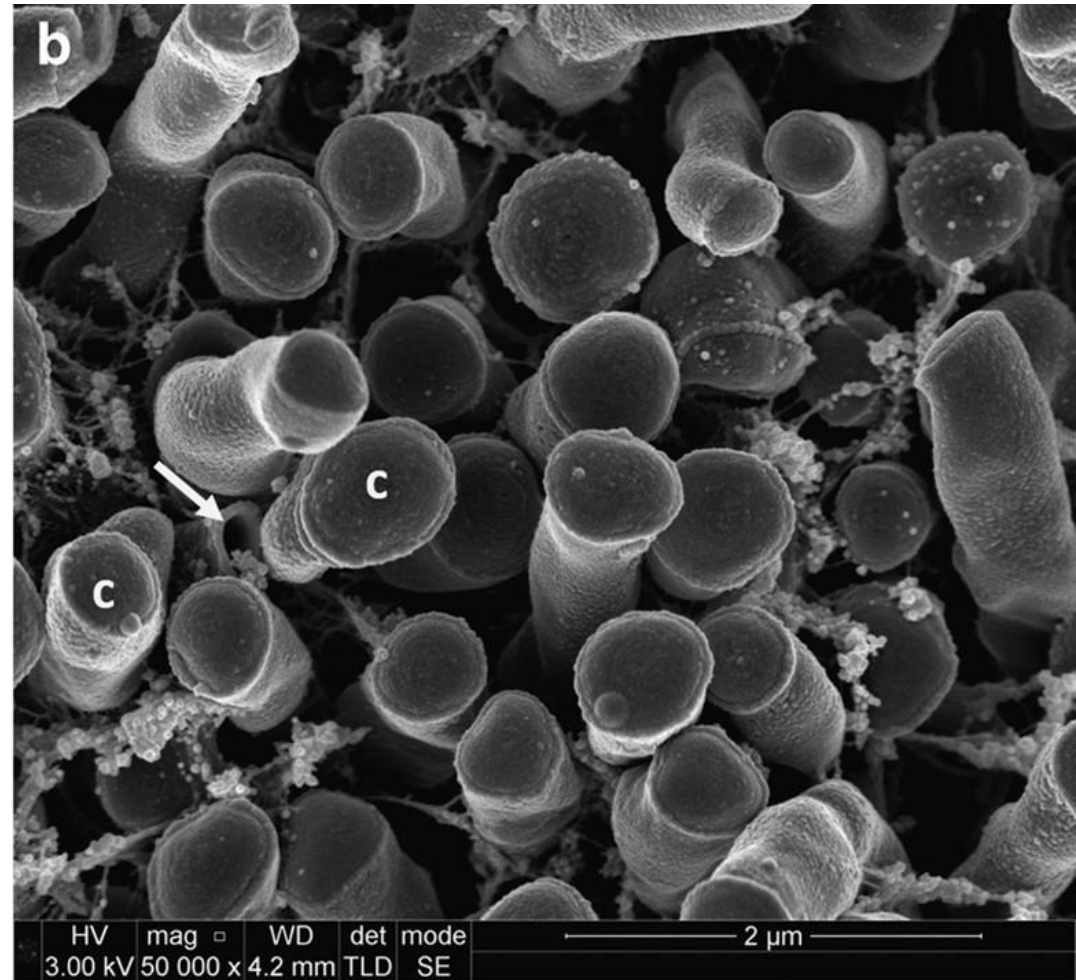
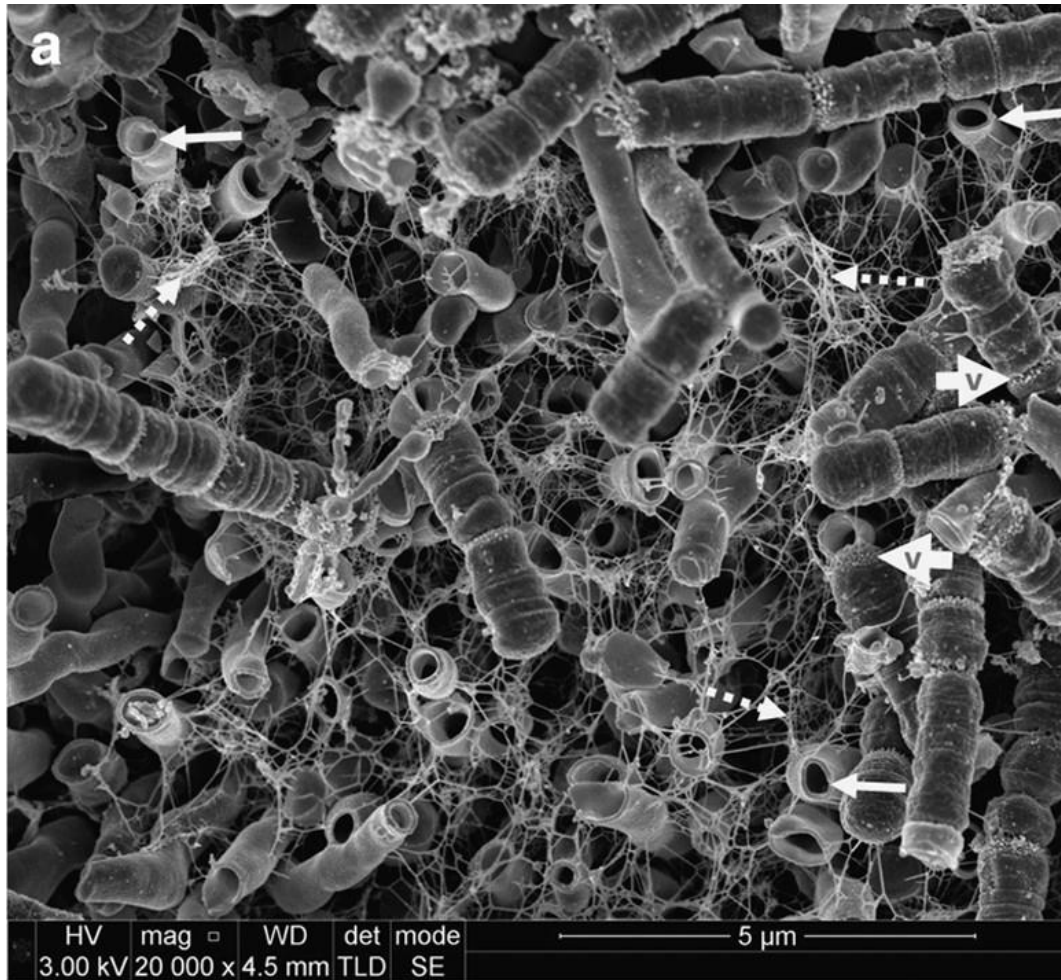


web of extracellular matrix material, rod-shaped cells



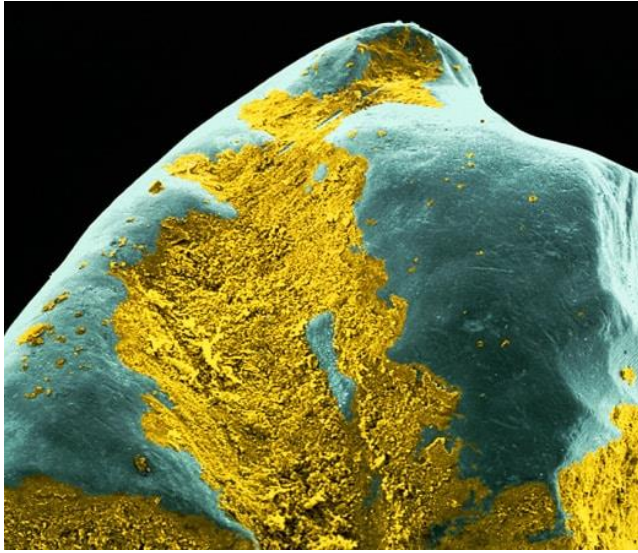
swollen rod morphology: TM7 phylum (t), Spirochaeta bacteria (s), arrows – membrane-associated vesicles

Ultrastructure of dental plaques II



arrow: open tubules, broken arrow: extensive web of extracellular strands, short rod-shaped microorganisms,
v: vesicles, c: cells

Ultrastructure of dental plaques III

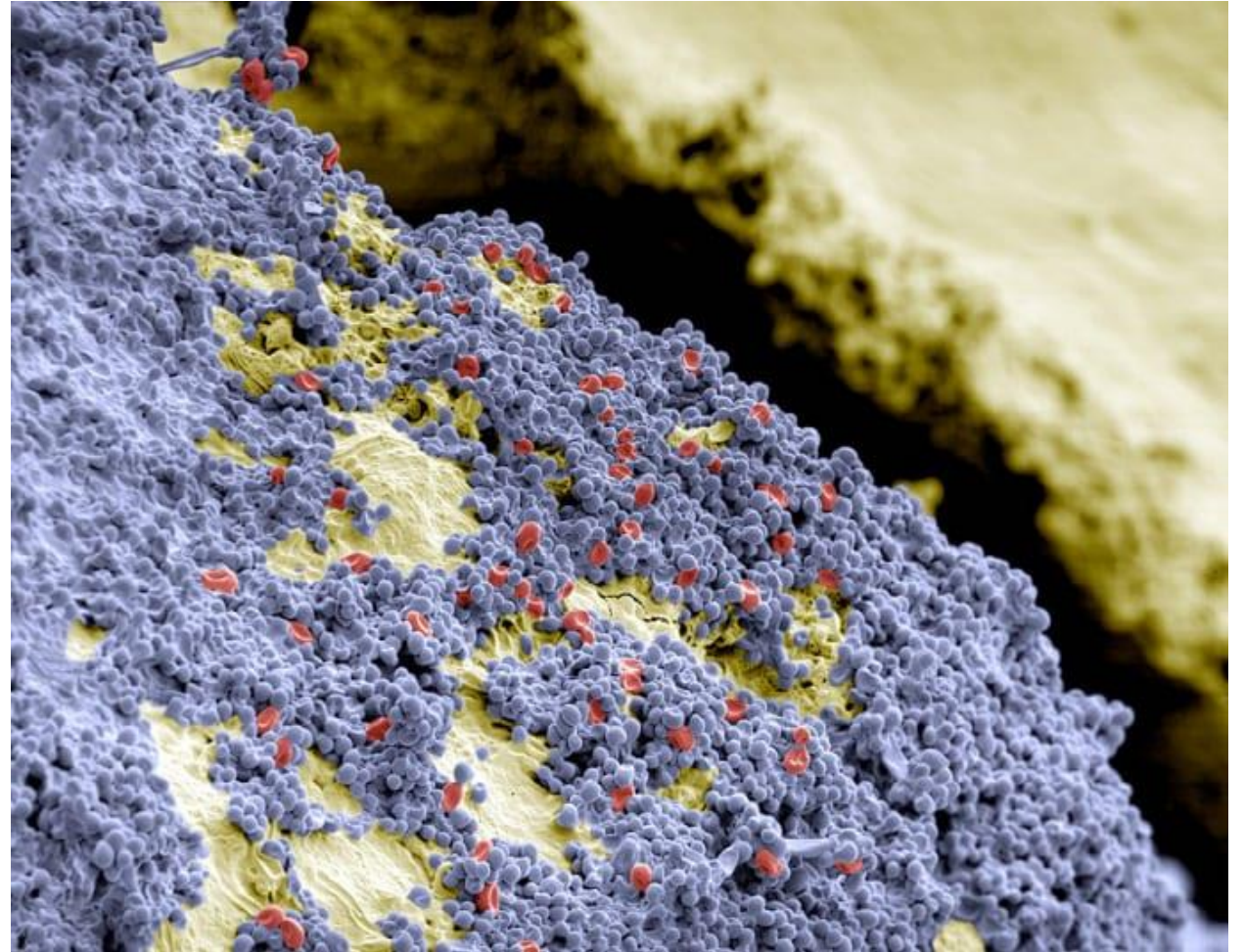


yellow: bacterial plaque



Dental plaque, biofilm (400x)

Blue: colony of coccid bacteria, red: RBC



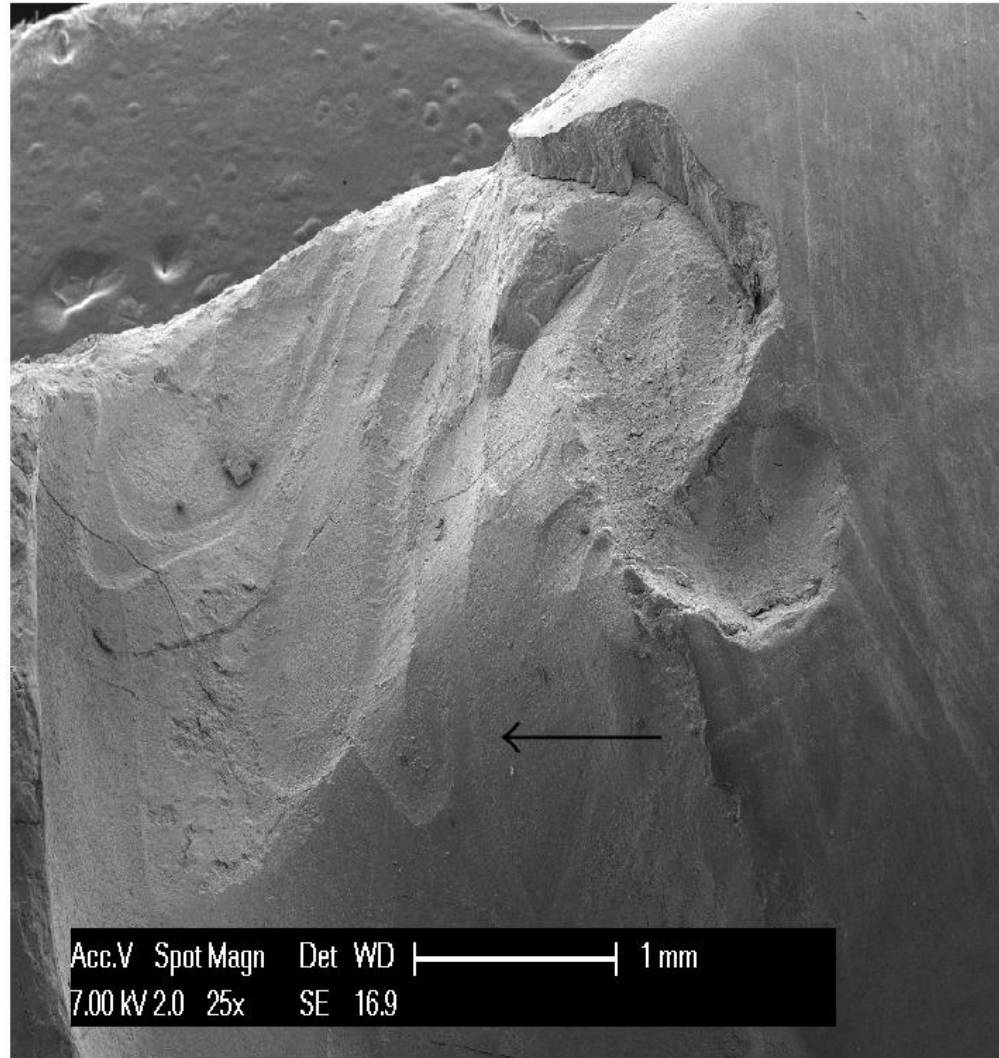
<https://www.telegraph.co.uk/news/picturegalleries/howaboutthat/11067916/Plaque-attack-Close-up-images-of-teeth-reveal-what-lives-in-your-mouth.html>

Types of dental wear

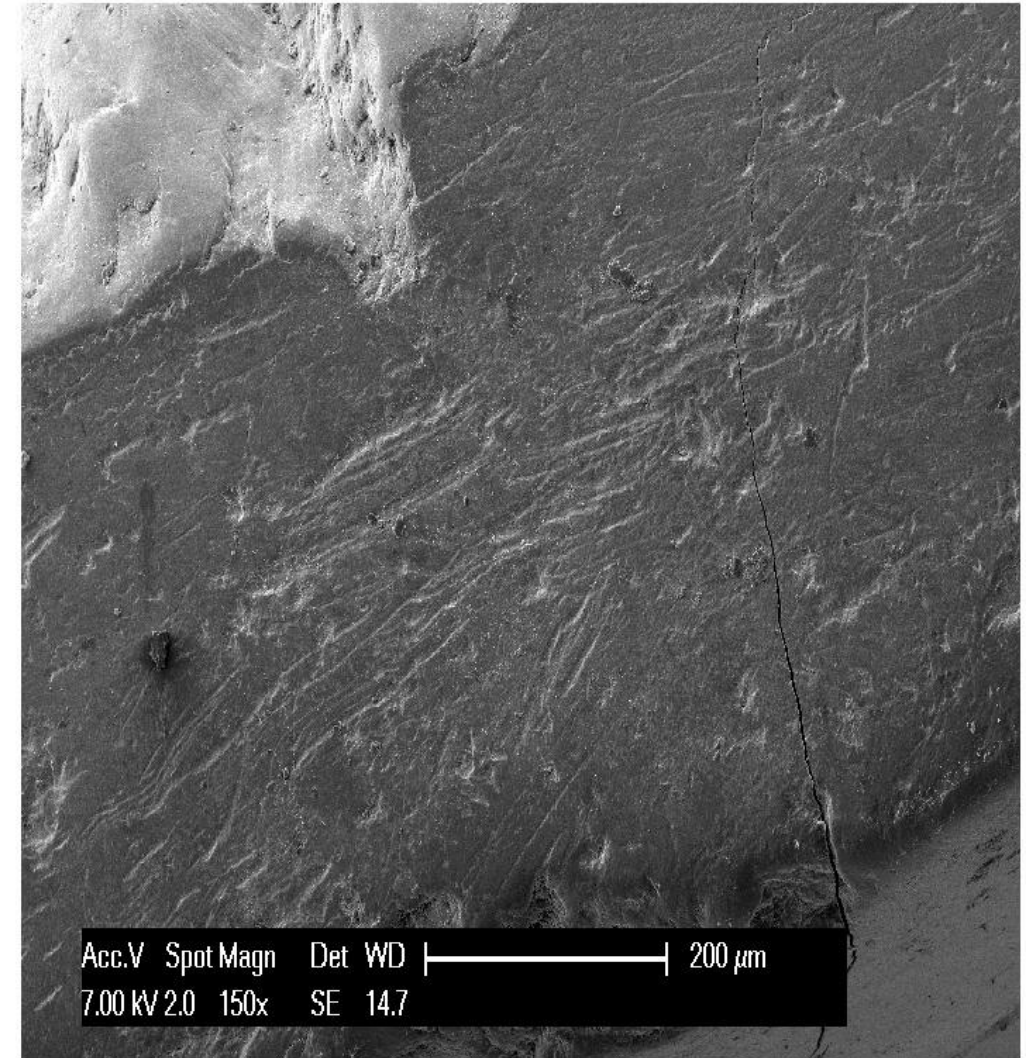
loss of mineralized tissue unrelated to bacterial action

1. **Erosion (chemical):** dissolution of dental tissue caused by acidic agents (extrinsic and intrinsic factors) food, drinks, reflux, bulimia, anorexia
2. **Abrasion (mechanical):** interaction between teeth and exogenous objects: toothpicks, dental floss, toothpastes, toothbrushes (hard bristles, too much pressure is applied when brushing)
3. **Attrition (mechanical):** caused by excessive functional or parafunctional forces and bruxism
4. **Abfraction (mechanical):** when the tooth is subjected to extreme stress and fatigue

Abfraction and attrition of enamel

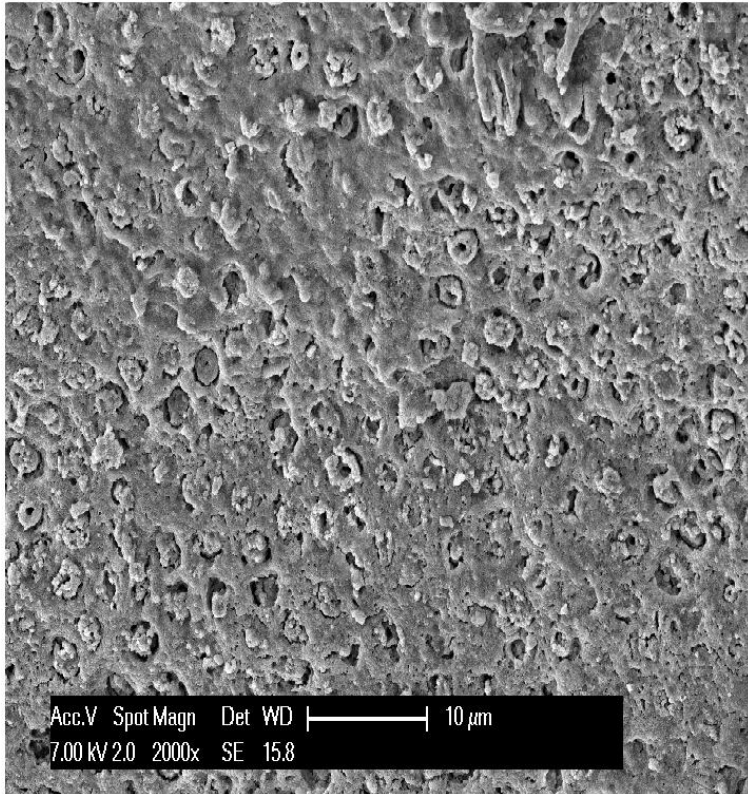


enamel abfraction: multiple cavities, partially overlapping furrows

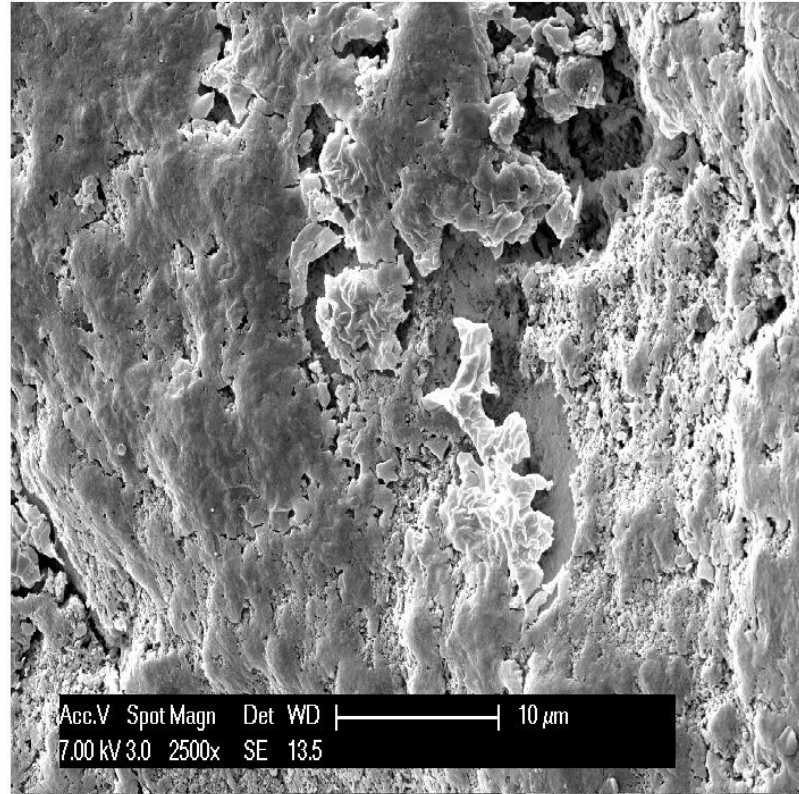


enamel attrition: scratches, stripes, and striations

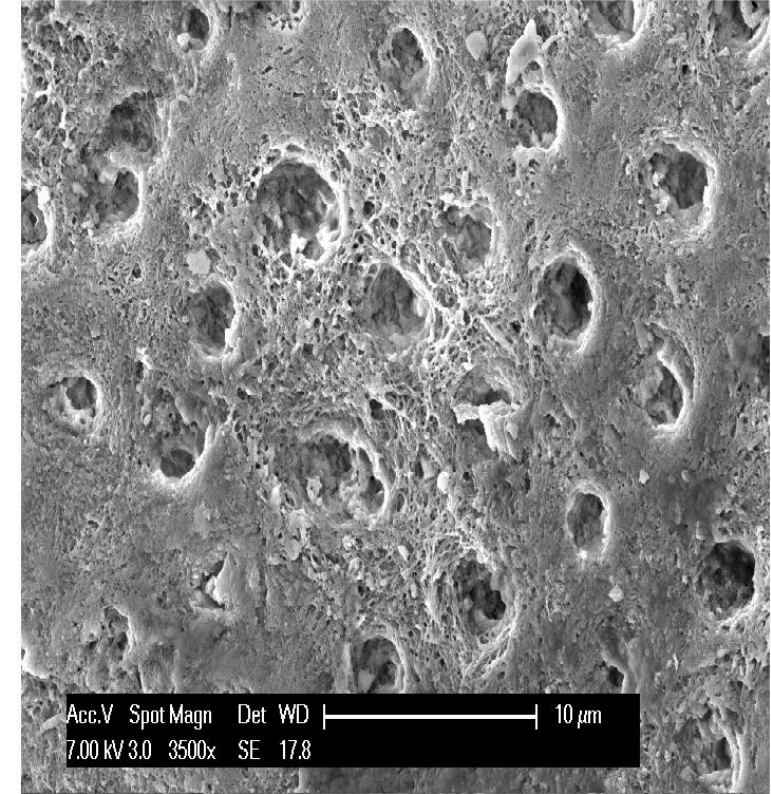
Lesions of dentin



In advanced lesions, there is clear dentin exposure with remains of the smear layer on the surface.



In advanced lesions the dentin is covered with crystallized debris.



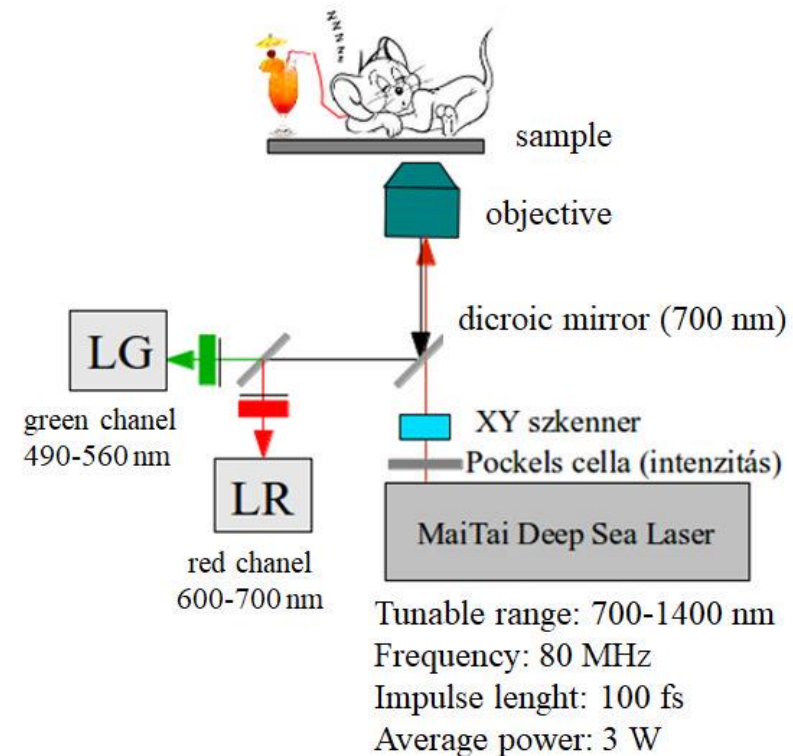
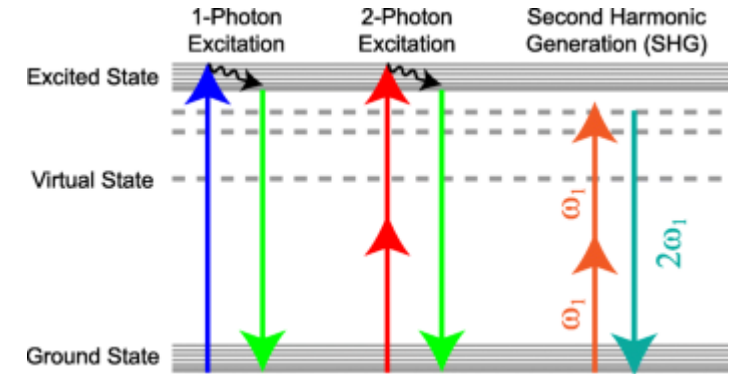
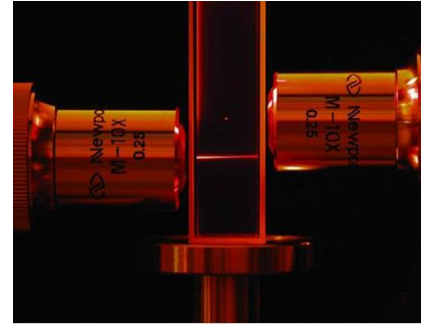
In erosion lesions, the tubules have rounded openings; the collagen matrix between them is eroded and demineralized.

Two-photon microscopy

What can be examined?

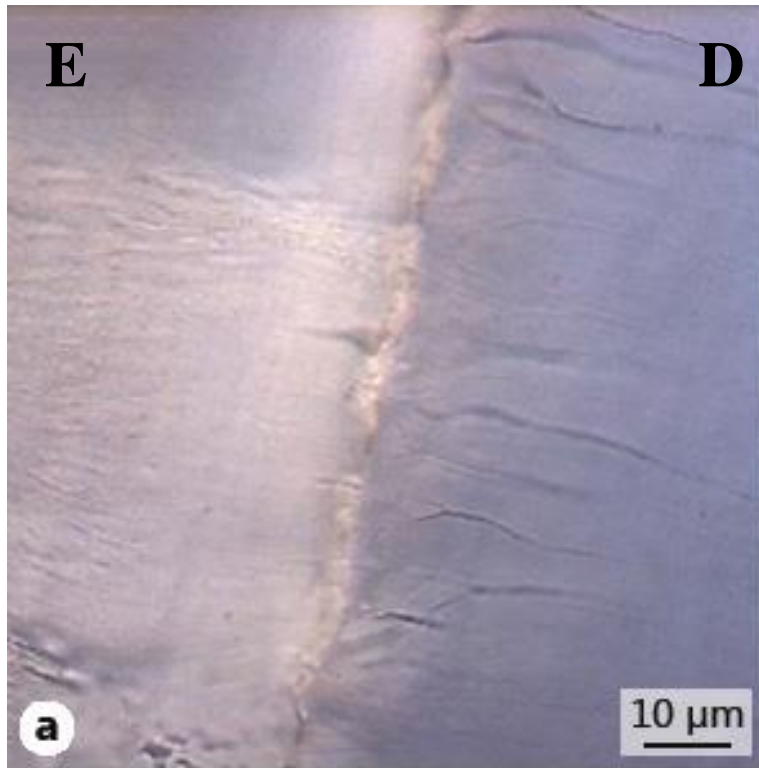
1. autofluorescence and second harmonic generated signal from organic components of dentin (e.g. collagen) under normal and pathological conditions
2. Structure, orientation and periodicity of collagen fibers

Second-harmonic generation (SHG, also called frequency doubling) is a nonlinear optical process in which two photons with the same frequency interact with a nonlinear material, are "combined", and generate a new photon with twice the energy of the initial photons (equivalently, twice the frequency and half the wavelength), that conserves the coherence of the excitation.

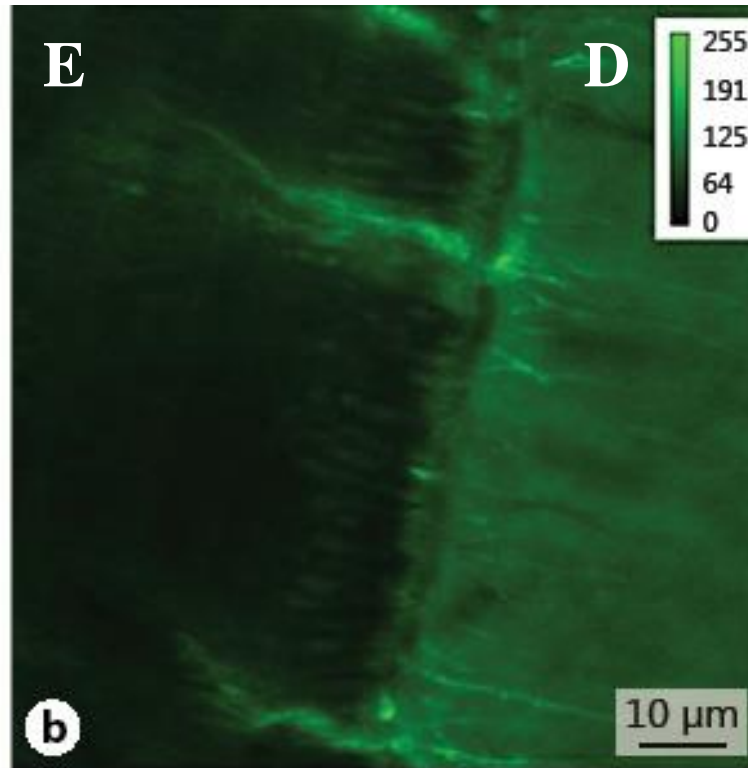


Normal dentin-enamel junction (DEJ)

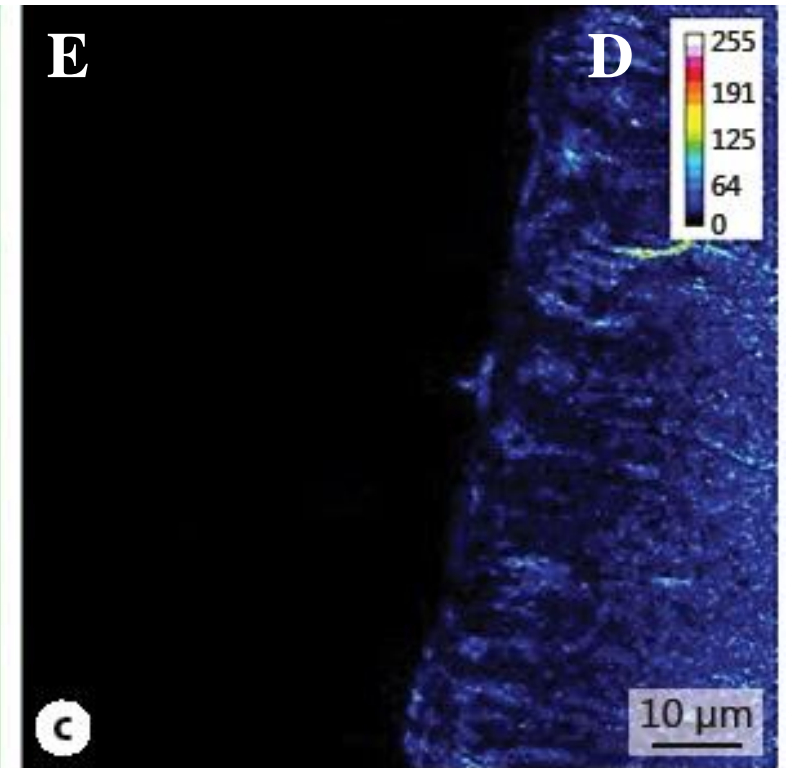
Bright-field



2PEF



SHG

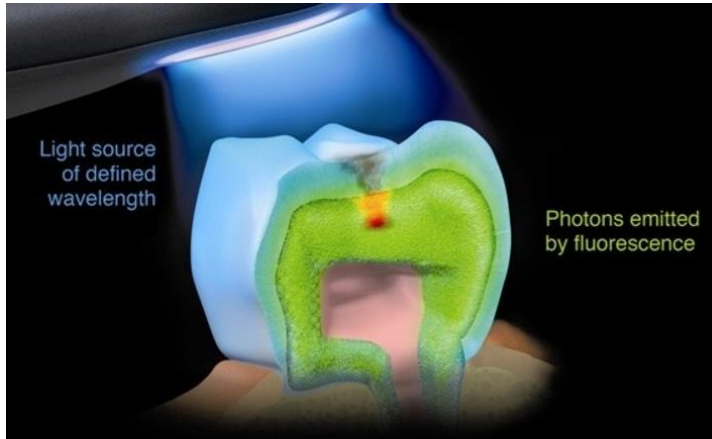


autofluorescence – organic
components (E + D)

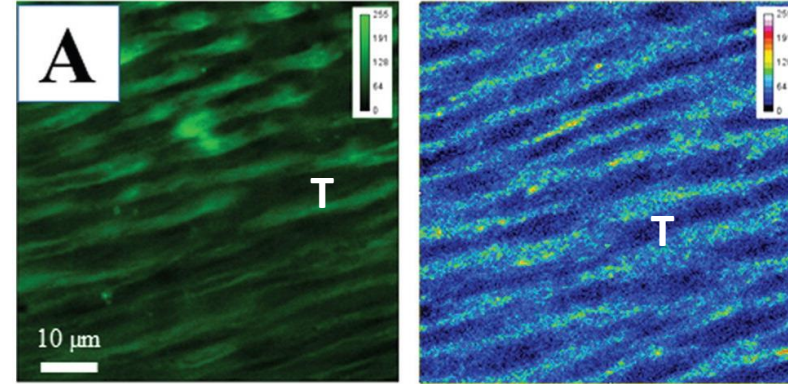
SHG signal only in dentin
– presence of collagen

The SHG/2PEF ratio can be a sensitive parameter to monitor caries development

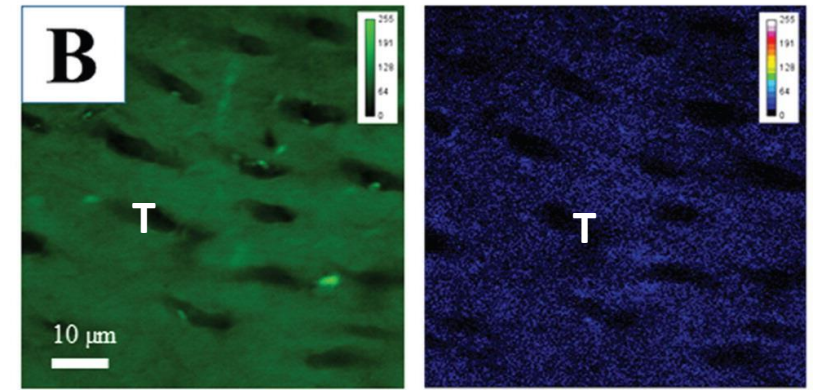
SoproLife camera – 450 nm



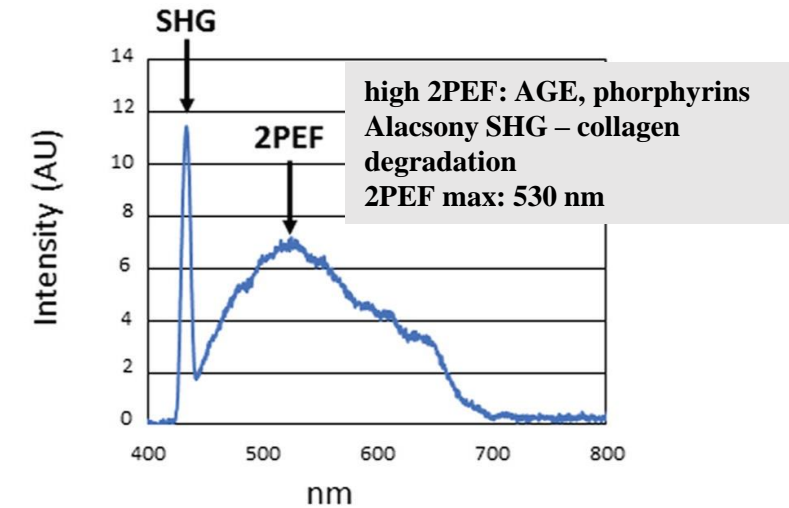
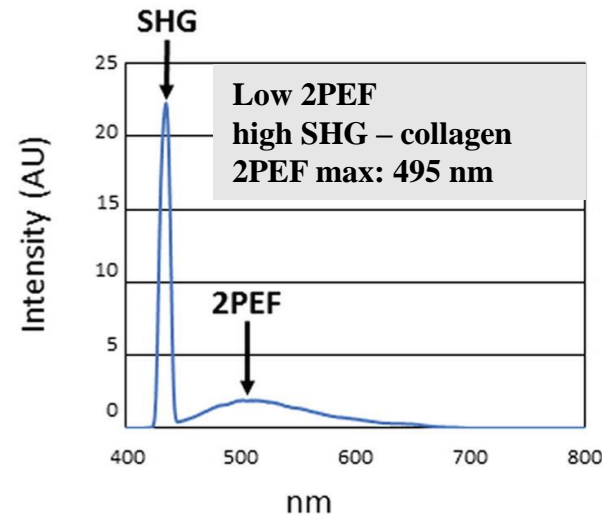
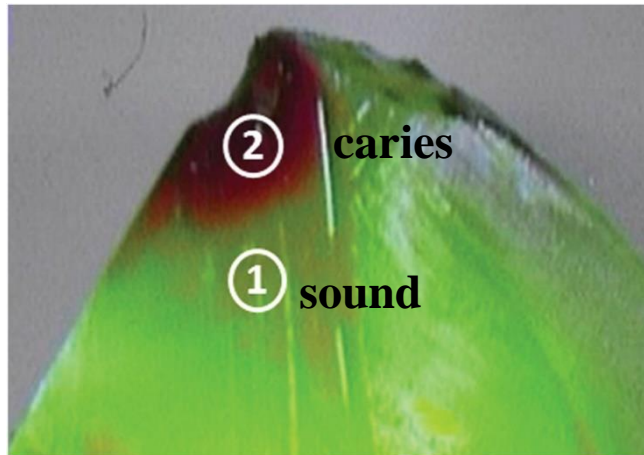
sound dentin



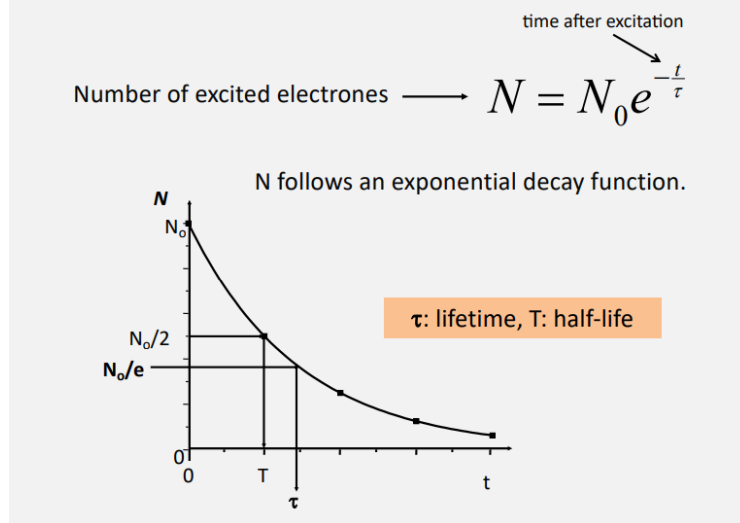
caries dentin



T: tubulus

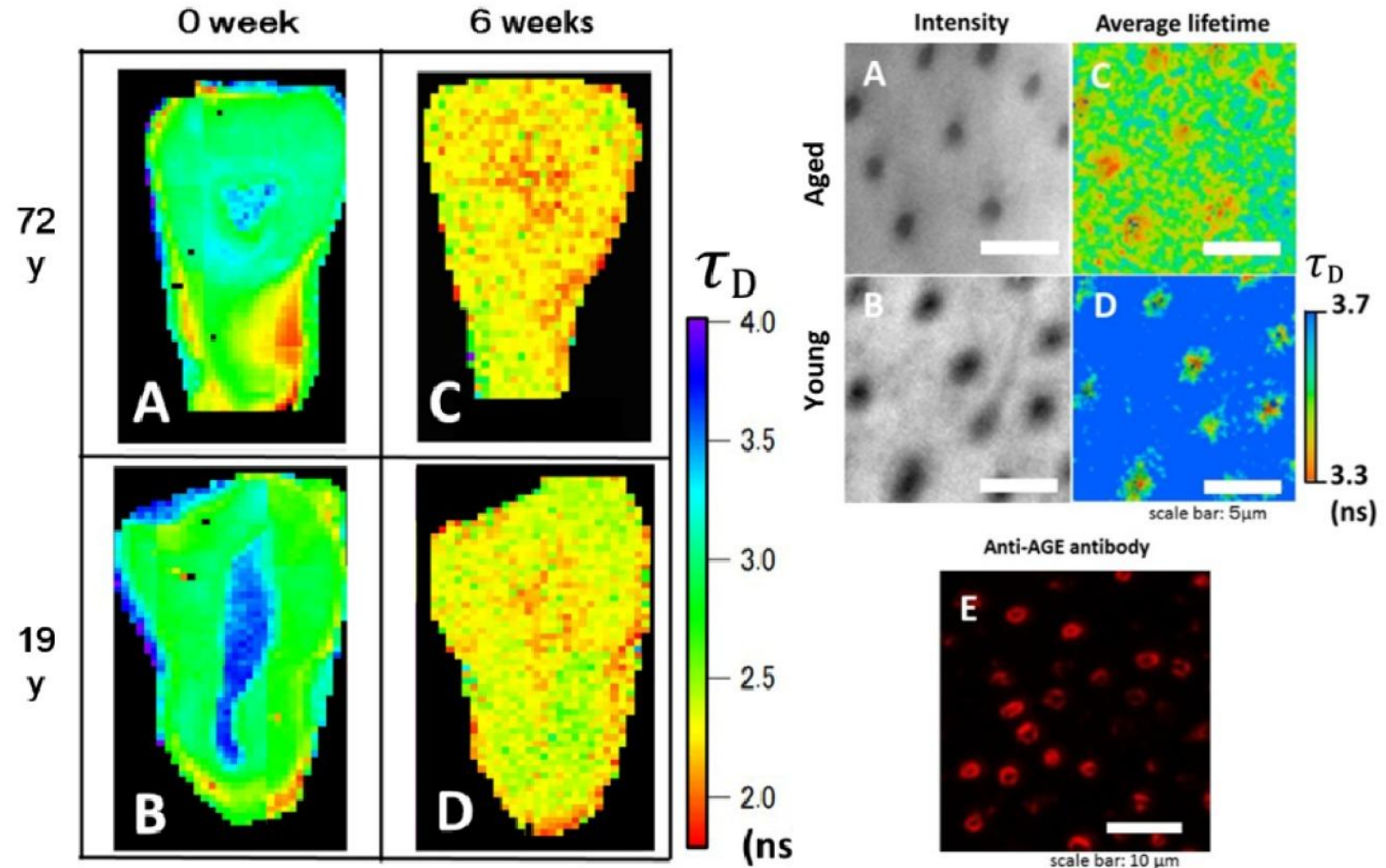


Decrease in fluorescence lifetime of dentin by ageing/glycation



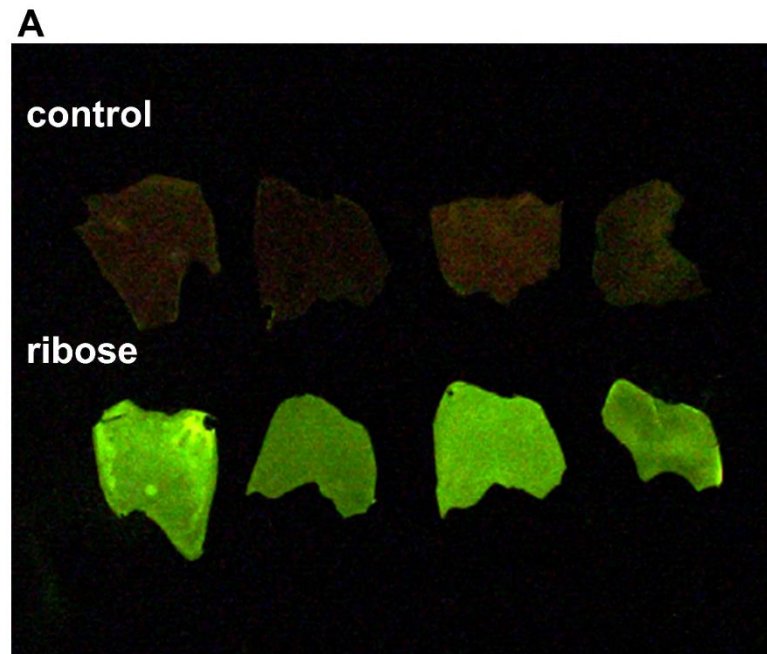
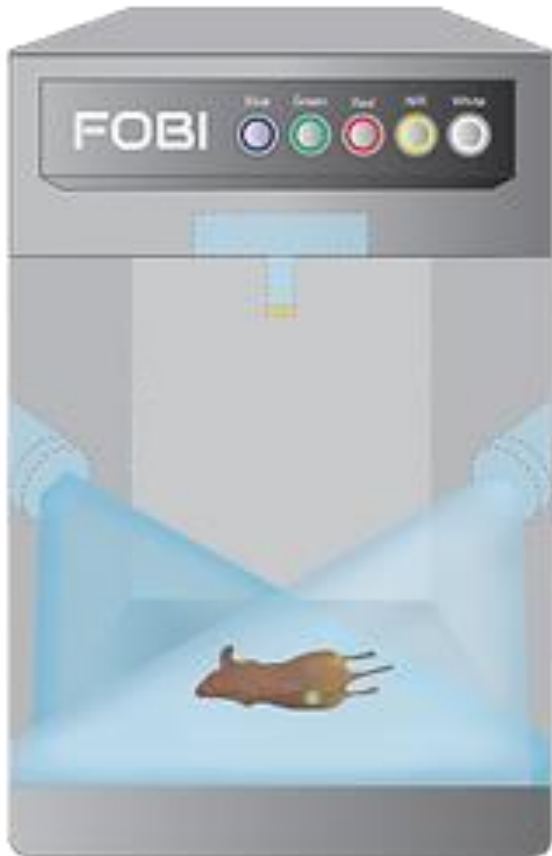
In sound dentin the aromatic amino acids of collagen have longer fluorescence lifetime. (0 week)

Due to glycation the accumulated autofluorescent glycated endproduct (pentosidine) dominates with shorter lifetime(6 weeks).

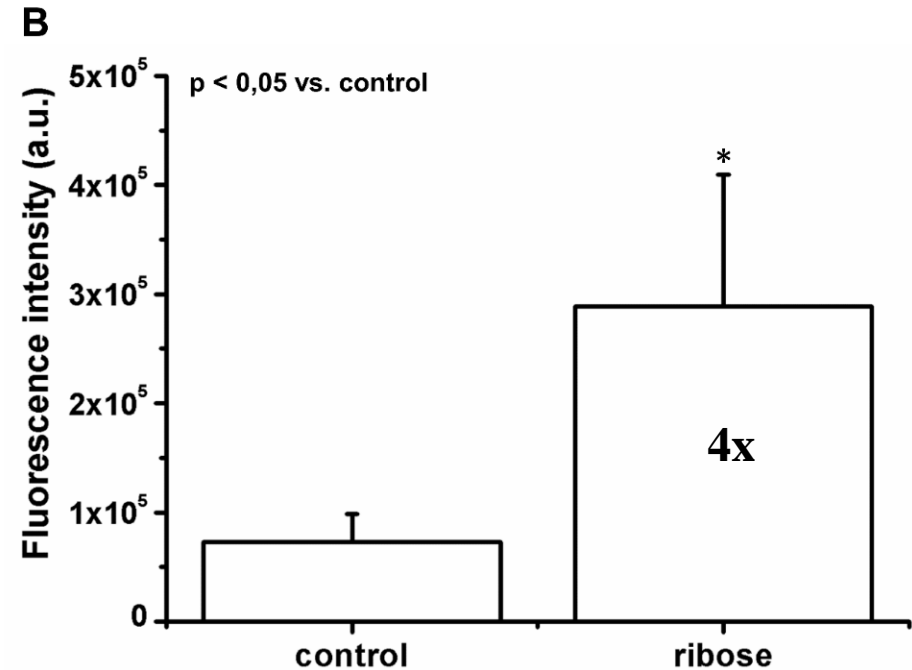


Detection of dentinal collagen glycation by using Fluorescence in Vivo Imaging (FOBI) system

Incubation of demineralized tooth sections in ribose solution –
aim: determination the extent of glycation/accumulation of AGEs



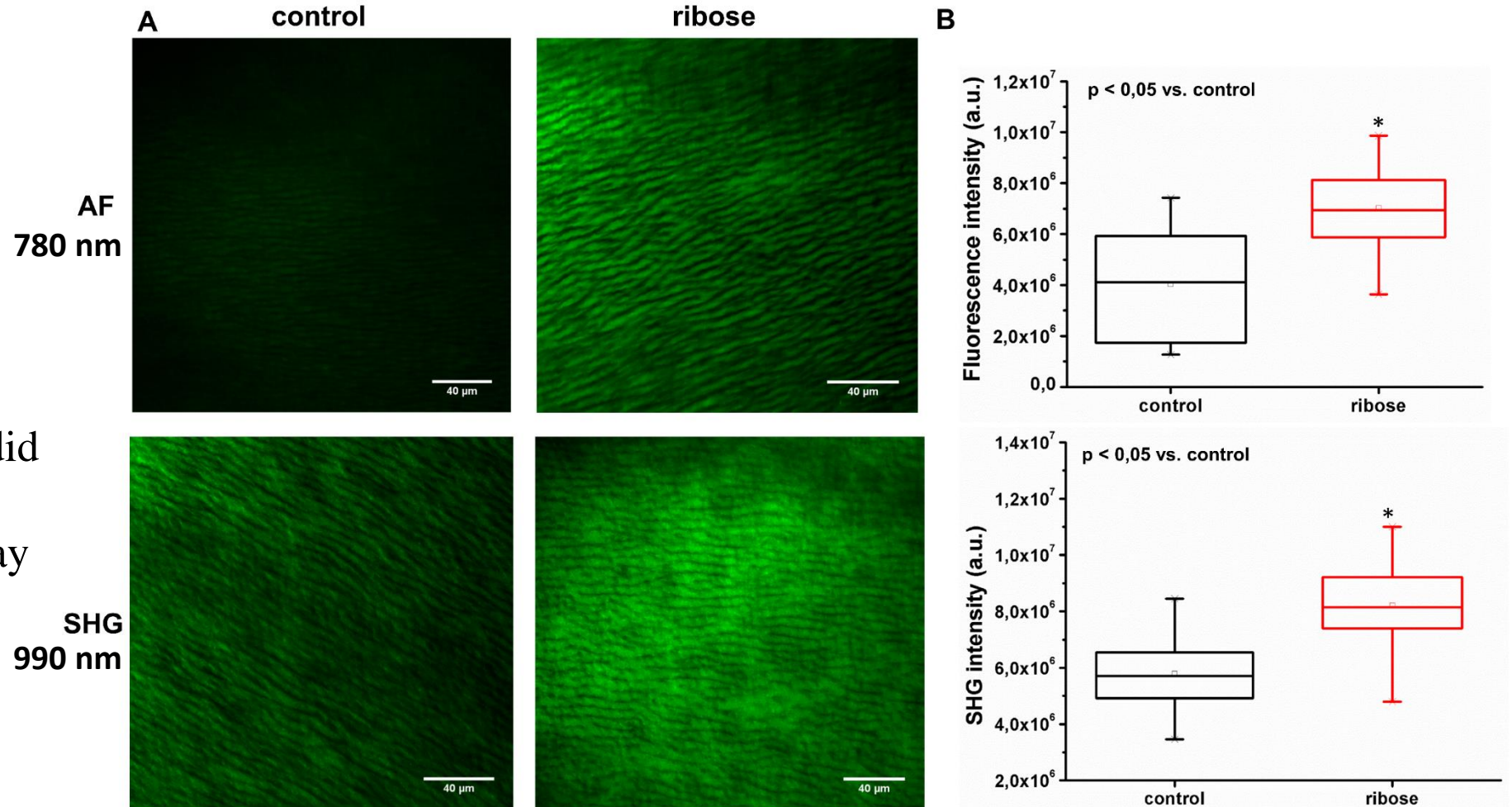
exc: 450 nm
em: 525 nm



As a result of glycation both the AF and SHG signal intensity increased

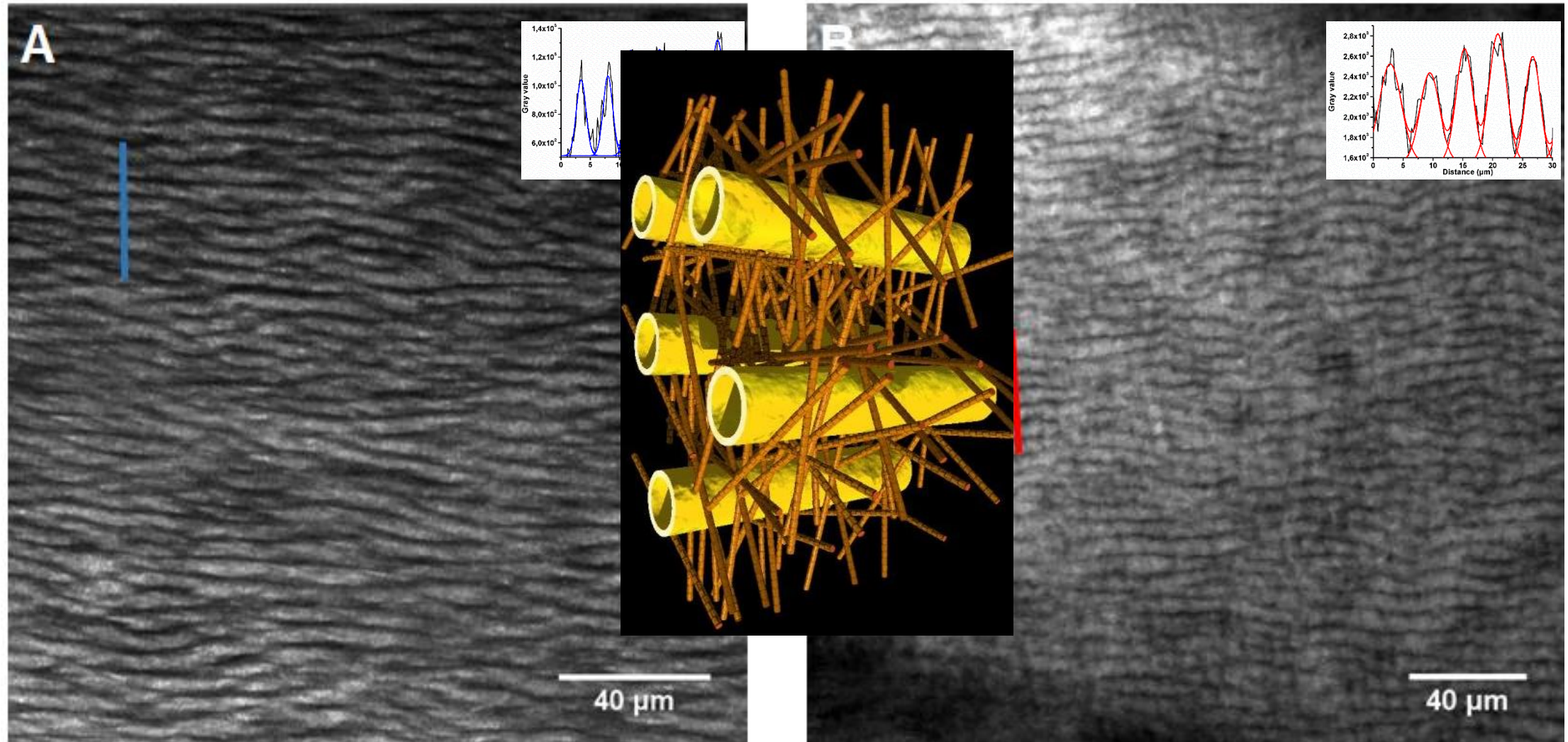
Conclusions:

- there is no enzymatic degradation (compared to caries)
- The collagen orientation did not change, thus, the accumulation of AGEs may have led to the higher emitted SHG signal



As a result of glycation the lenght of collagen fibers increased between dental tubules

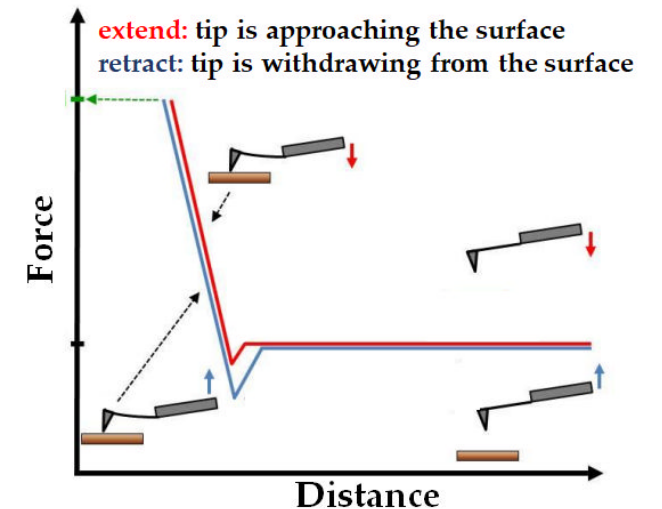
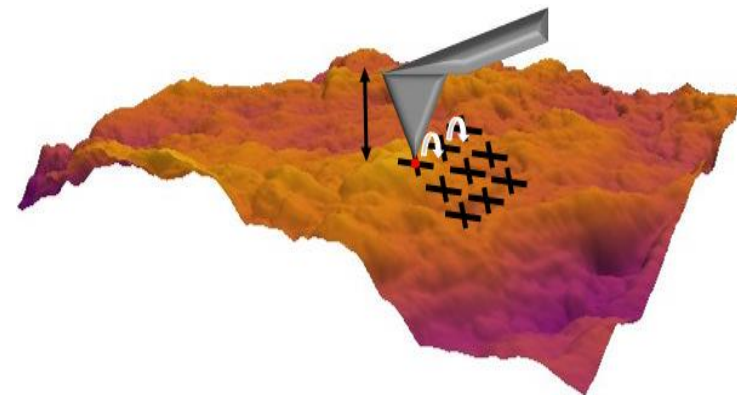
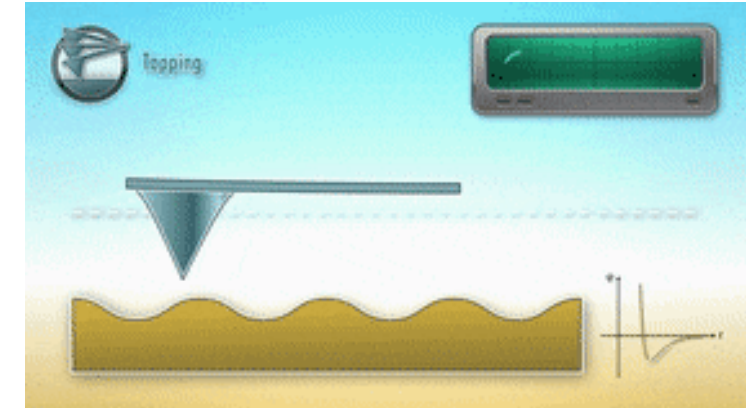
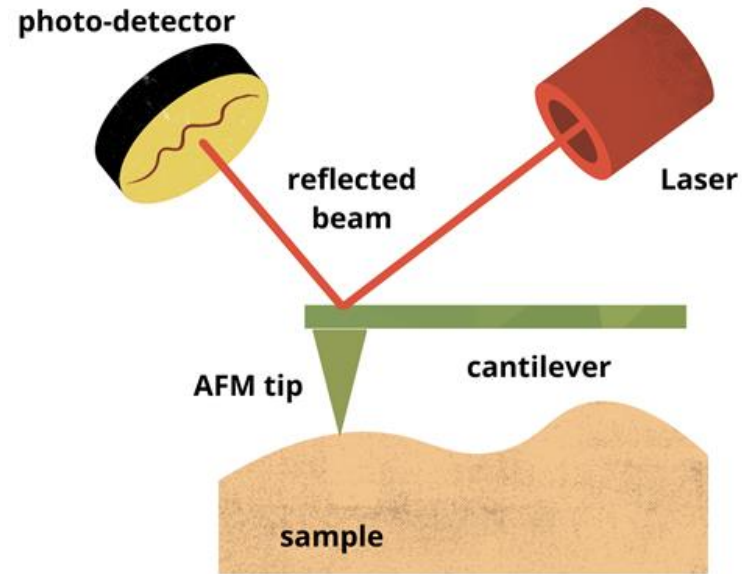
SHG images



Atomic force microscopy (AFM)

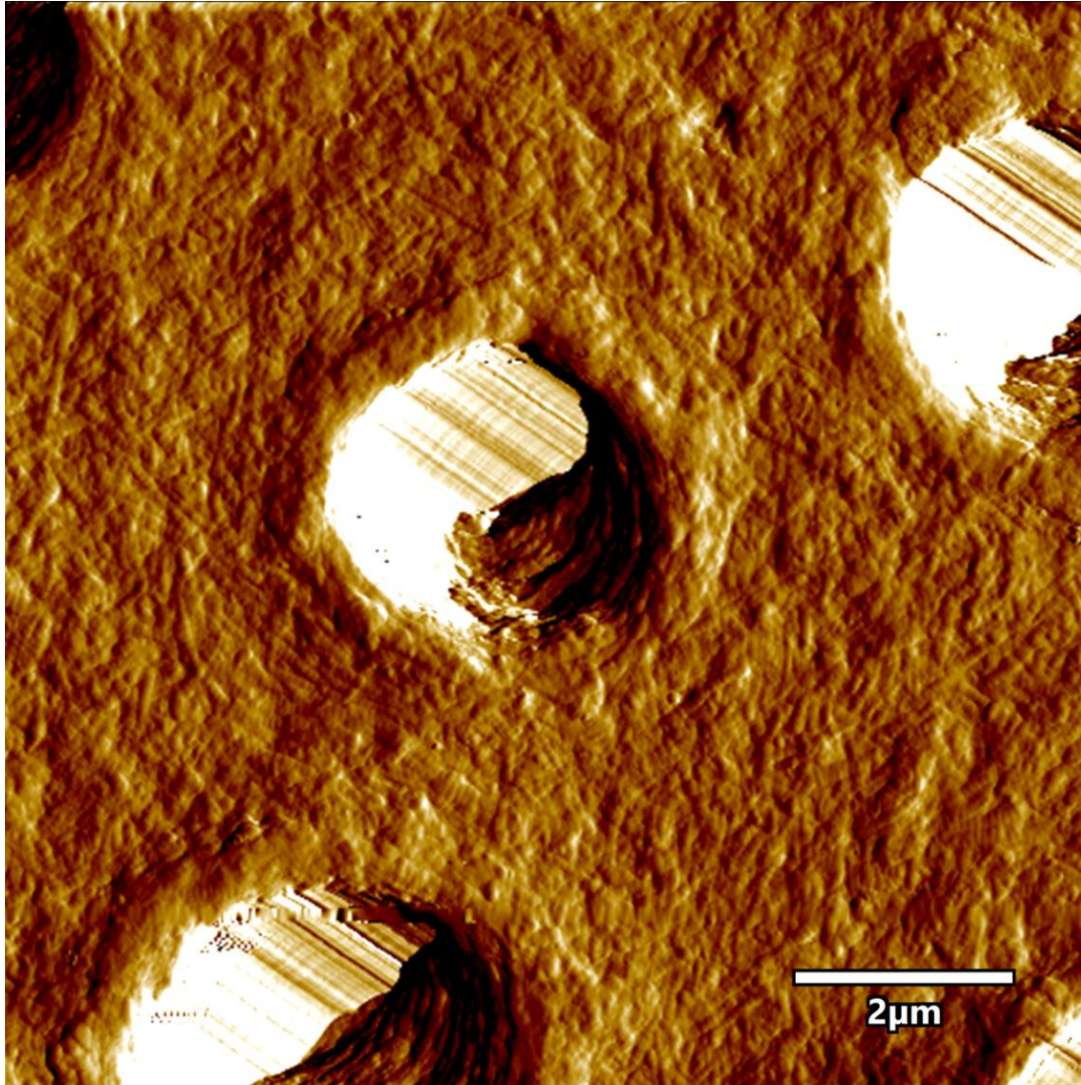
What can be examined?

1. Topography: structure of surfaces, roughness (e.g. effects of surface treatments)
2. Mechanics: Young' modulus of demineralized dentinal collagen (e.g. diabetes)

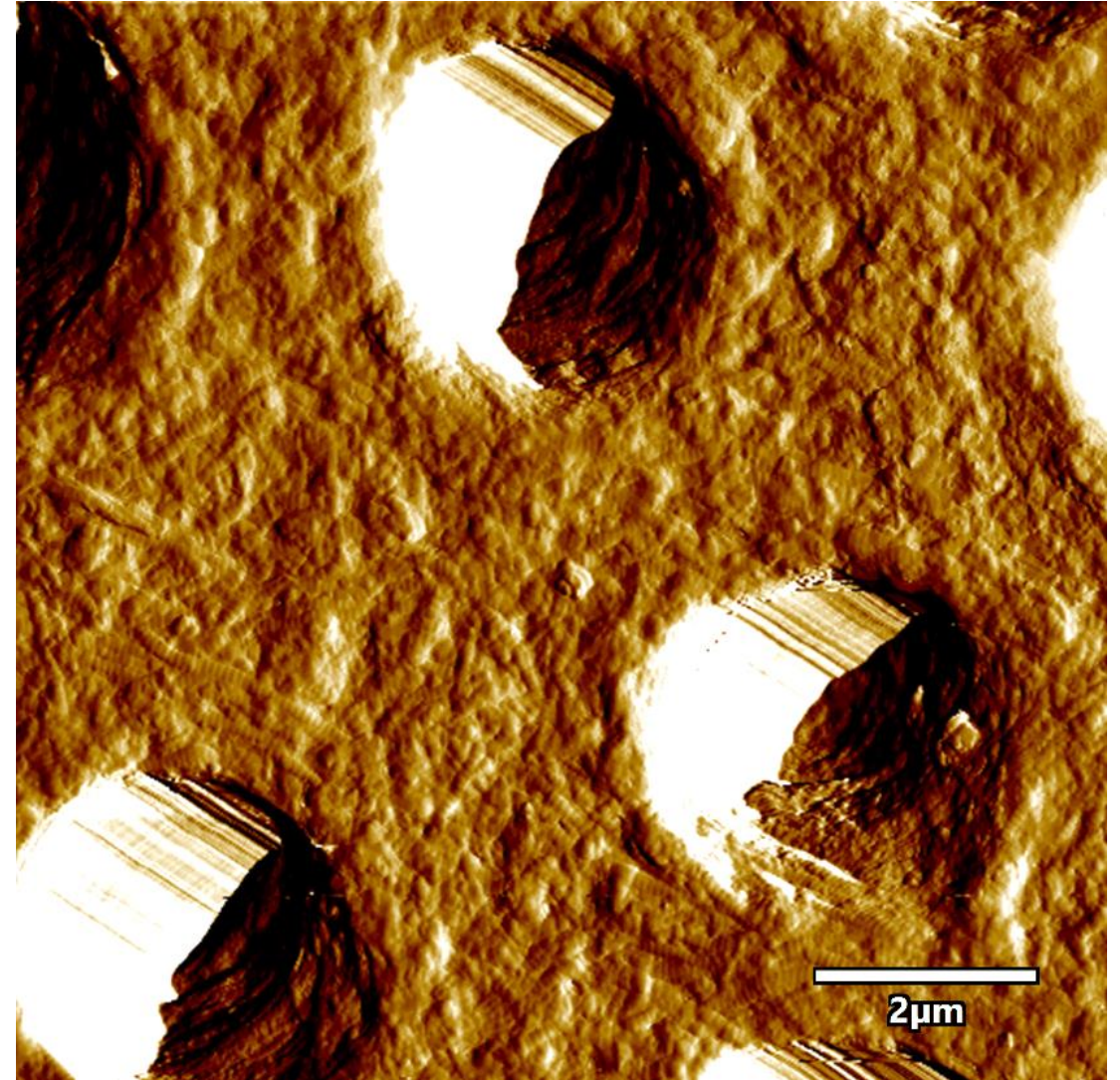


Glycation increased the roughness of intertubular dentin

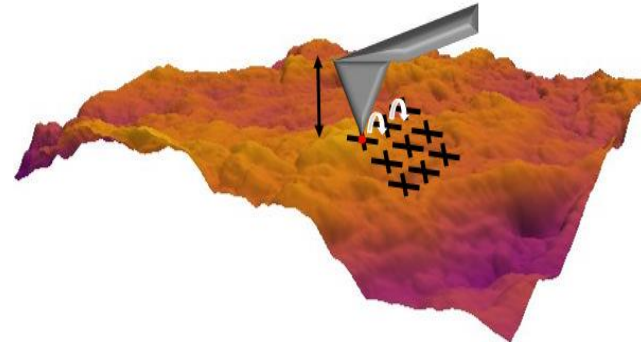
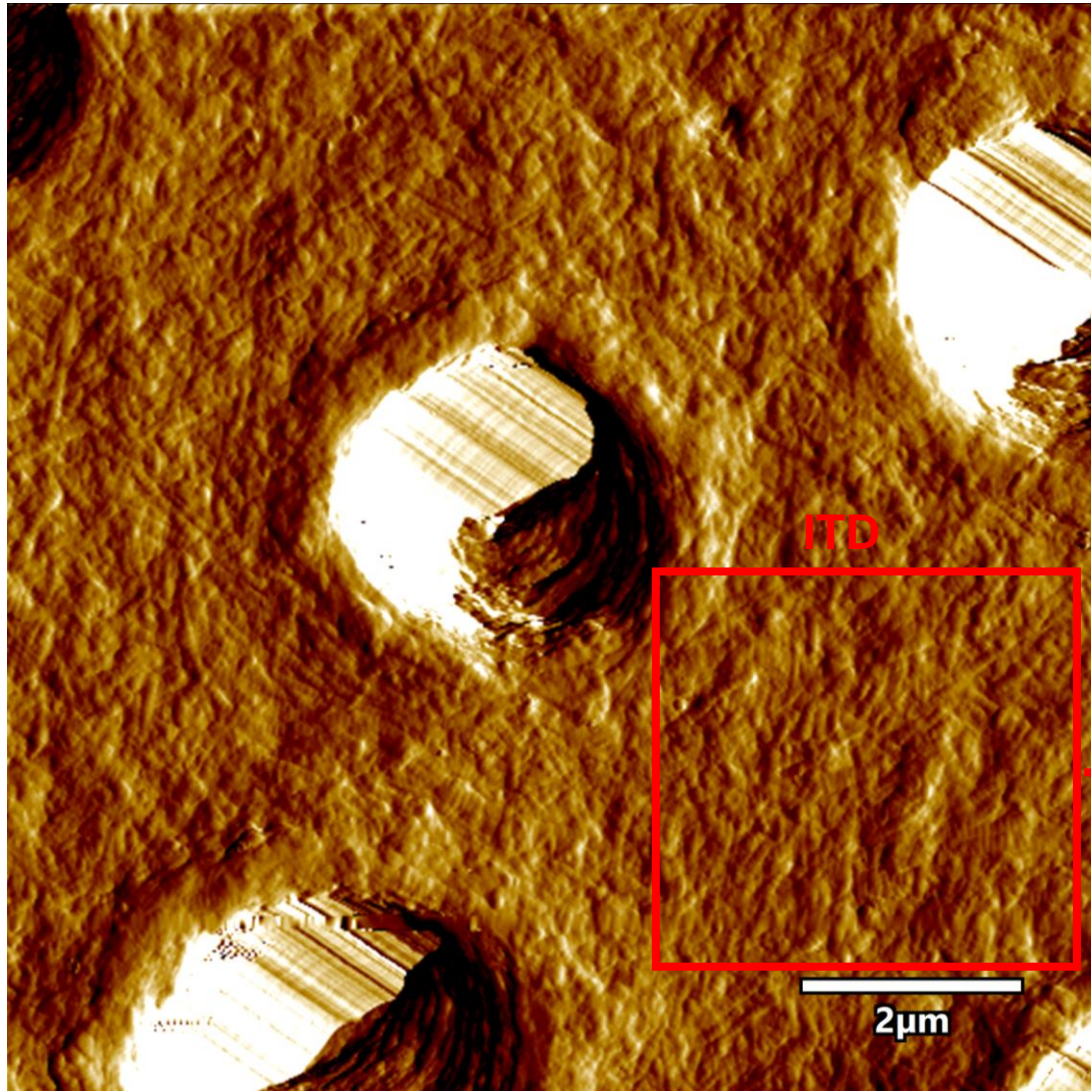
control



ribose

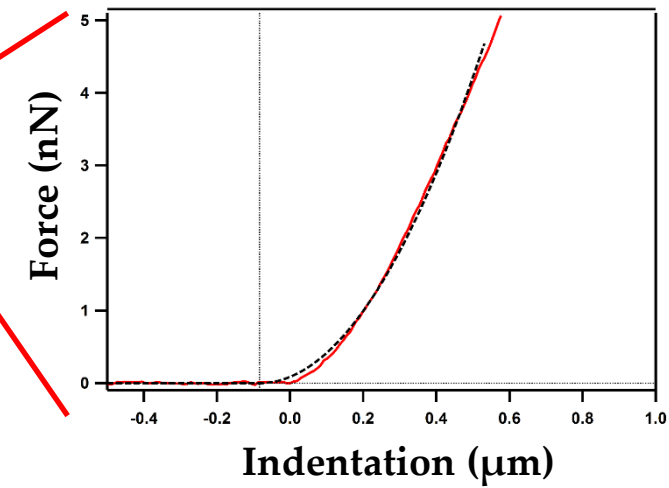
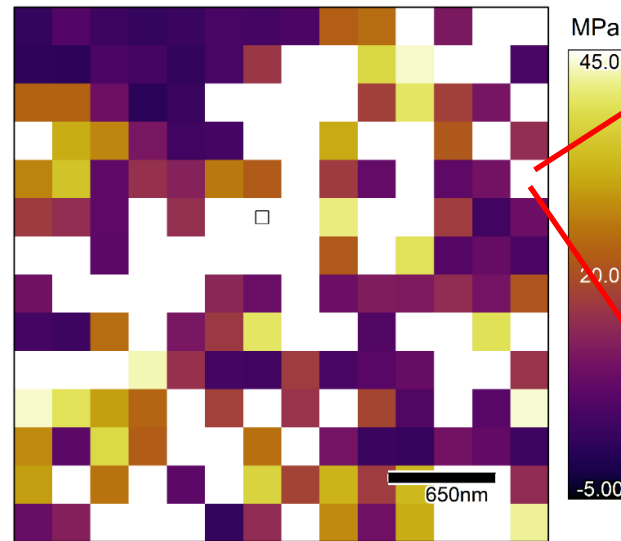


Force curve – force map

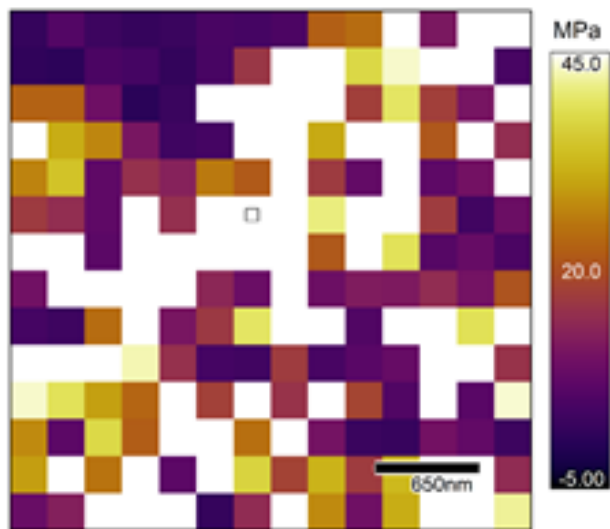
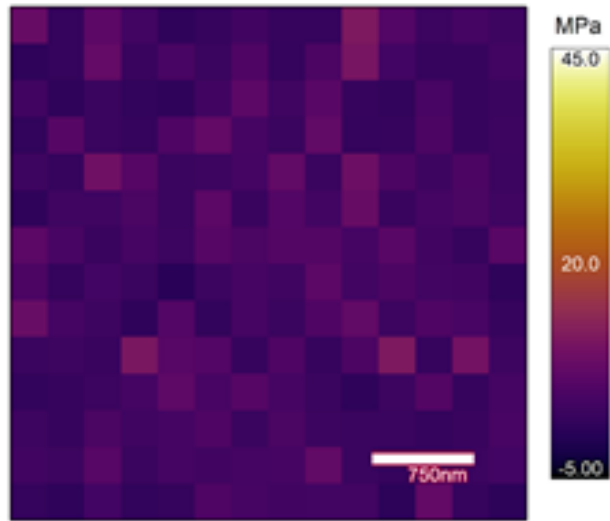


$$F = \frac{4}{3} E^* R^{1/2} d^{3/2}$$

E = complex Young's modulus of the system
 R = radius of curvature of AFM tip
 d = indentation depth

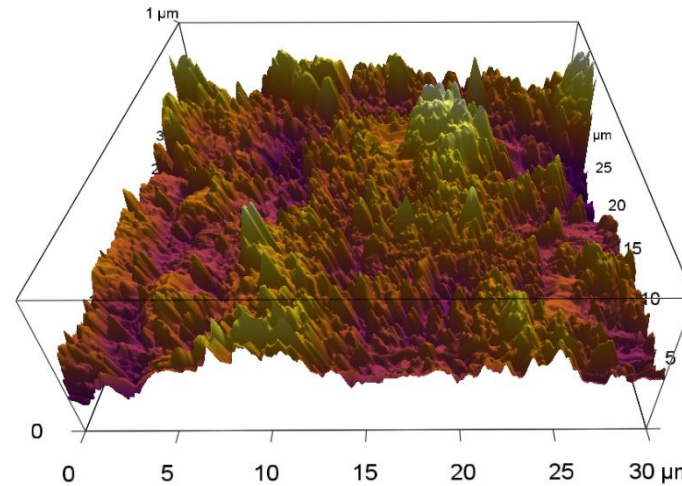
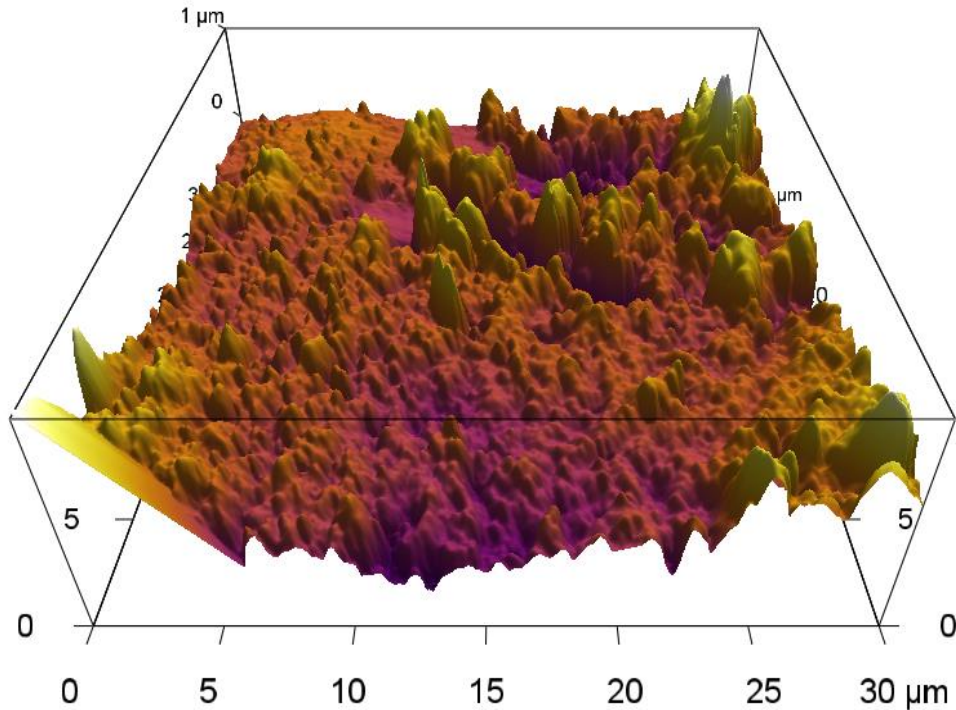


Glycation caused higher stiffness in ribose group

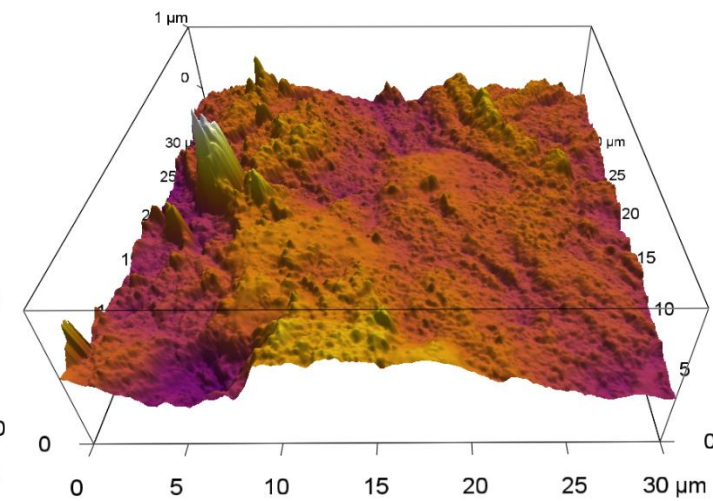


Effect of various surface treatments to enamel roughness

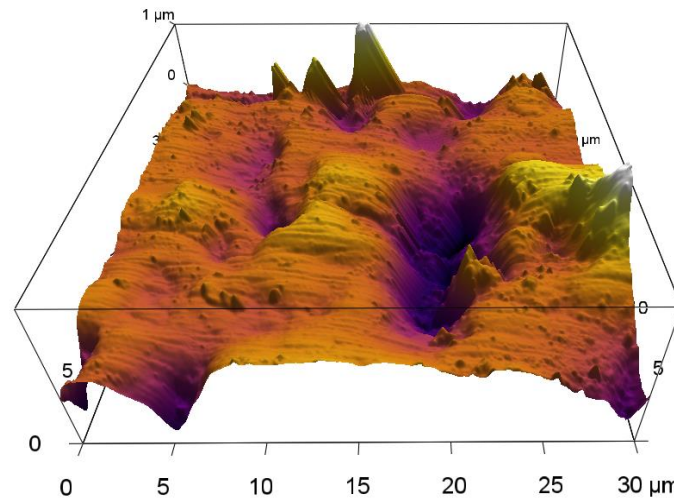
enamel slices without surface treatment



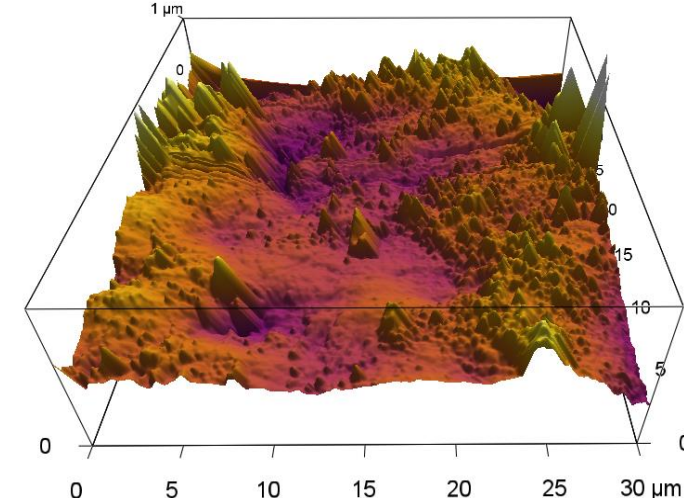
**air-polished with a 54-μm particle size
calcium carbonate prophylactic powder (5 s)**



**air-polished with a 54-μm particle size calcium
carbonate prophylactic powder (10 s)**



rubber diamond polisher



**polishing brush with built-in
silicon carbide abrasive particles**