Biophysics in dentistry

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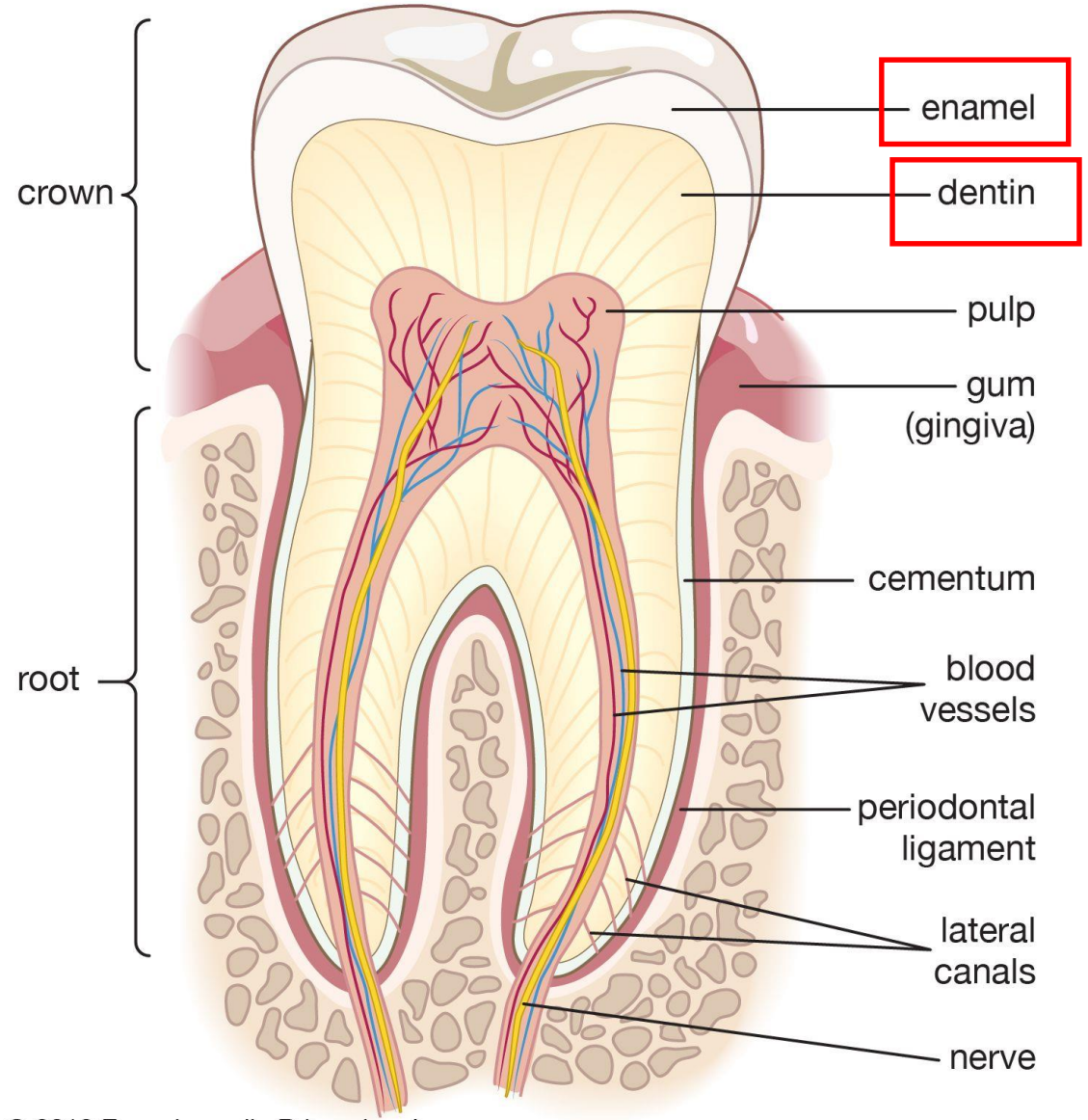
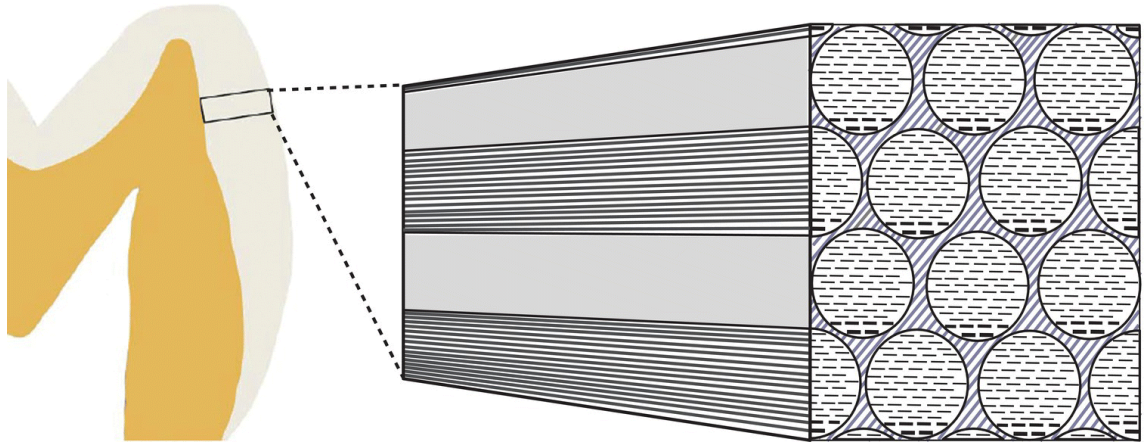
08/03/2024

The structure of tooth

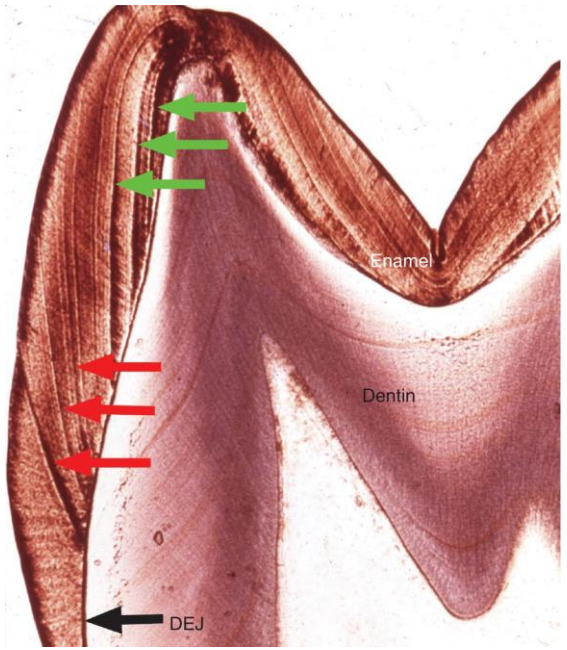


Structure of enamel

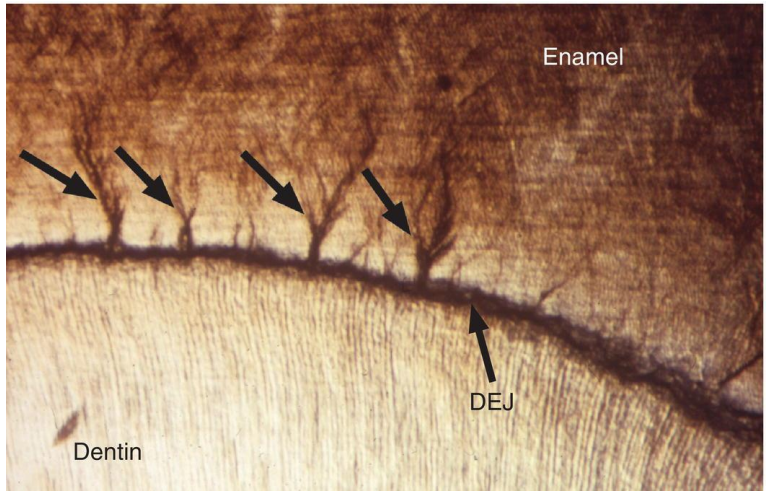
- highly mineralized, hardest substance in the human body
- transparent (dentin)
- hydroxyapatite 90%, carbonates, water, organic material
- does not contain collagen
- morphology: ameloblast – enamel rods, enamel prisms
- 4 μm diameter
- the long axis of the enamel rod is perpendicular to the underlying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



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



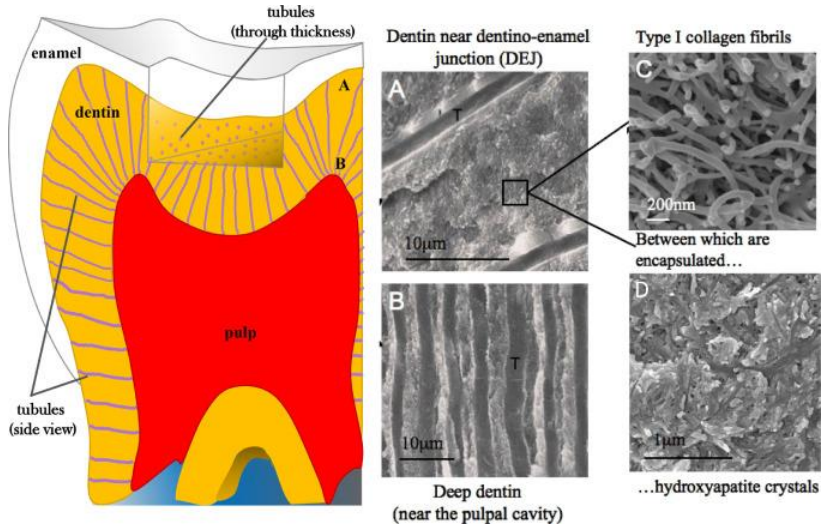
https://pocketdentistry.com/4-enamel/#R_c4-fig-0007



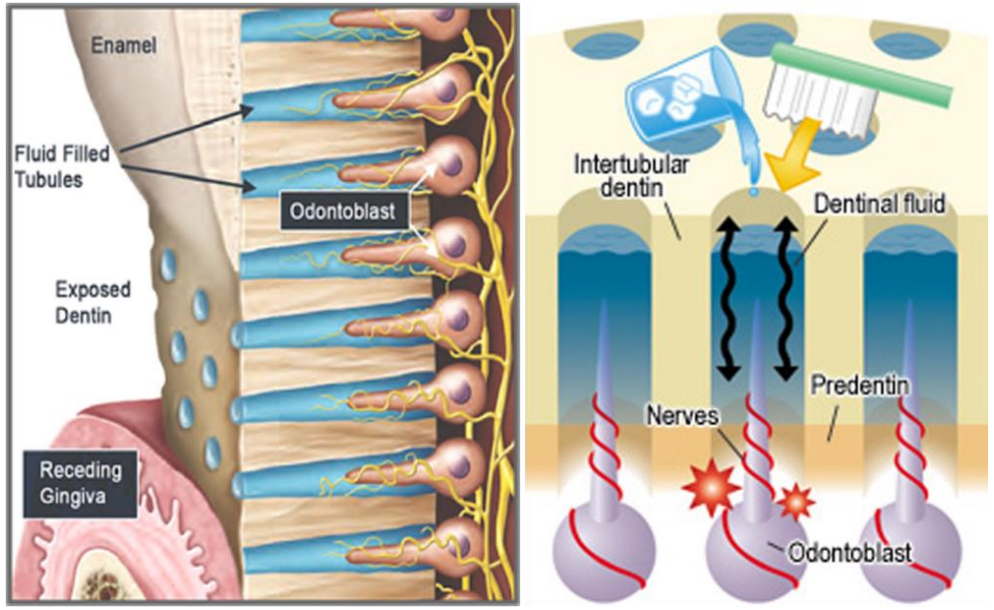
https://pocketdentistry.com/4-enamel/#R_c4-fig-0013

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



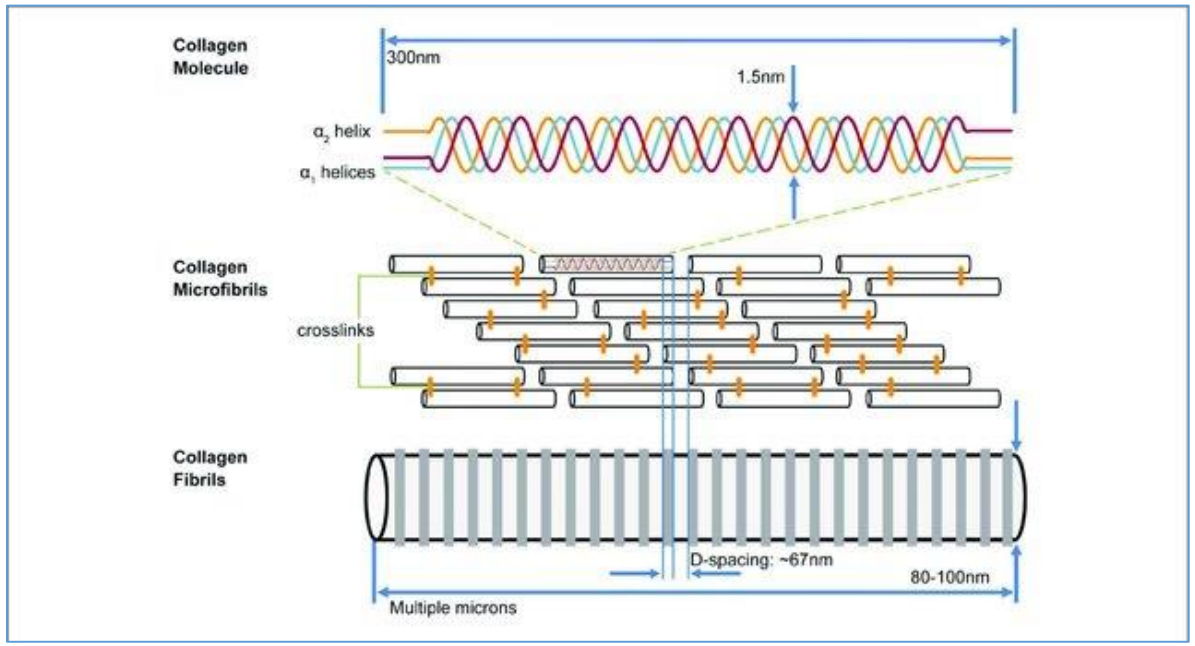
https://www.sciencedirect.com/science/article/pii/S1359646219305688

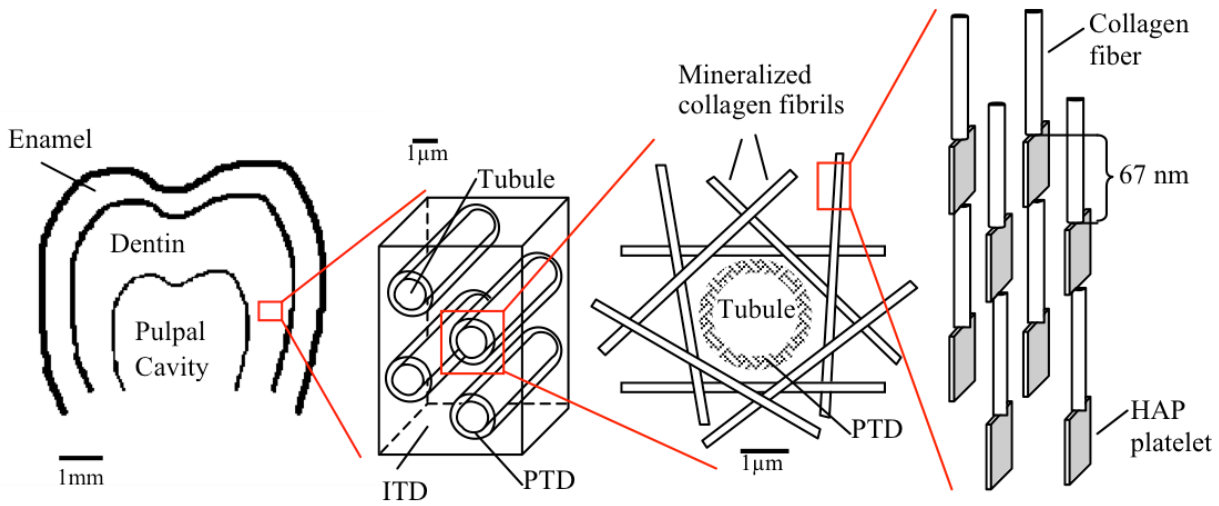


https://www.dentin.co/new-blog/2017/6/9/dentinal-hypersensitivity-hydrodynamic-theory

The hierarchical structure of collagen

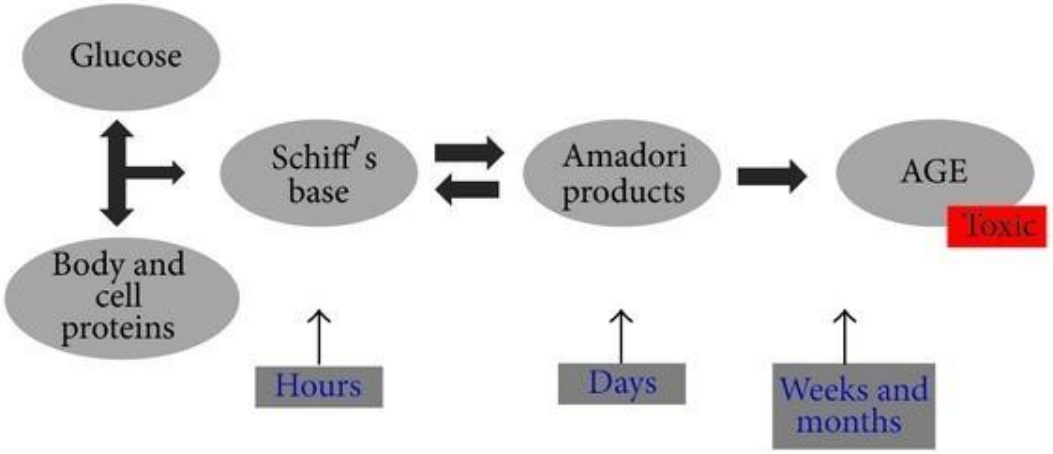
No turnover!!!





https://dunand.northwestern.edu/xray-dentin.shtml

Non-enzymatic glycation of collagen fibers



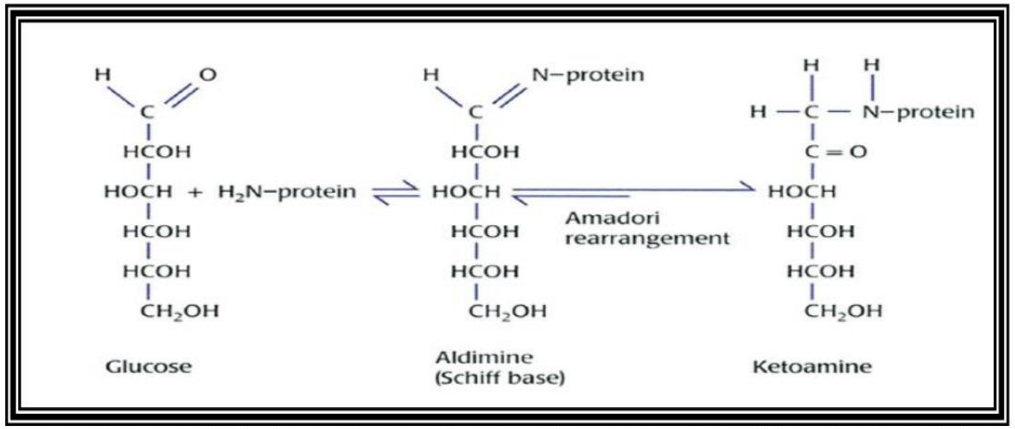
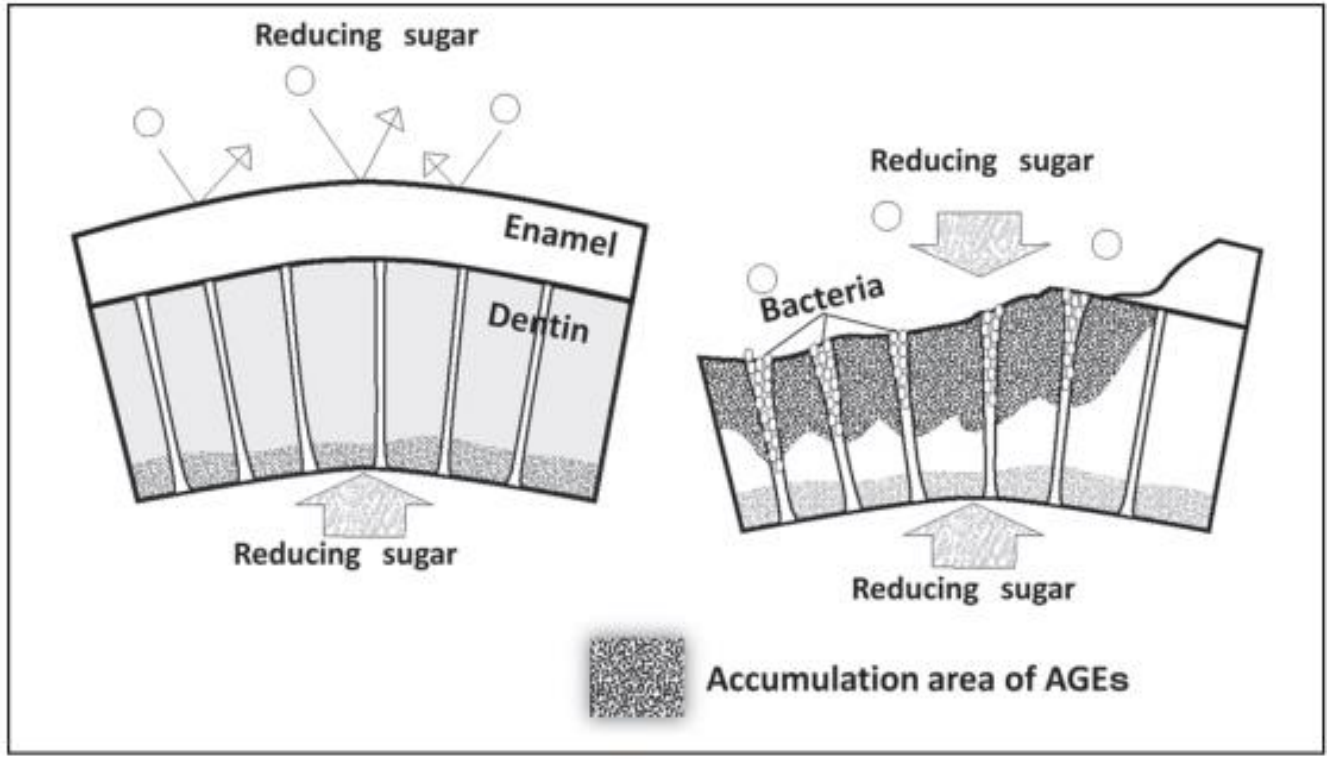


Figure 1: The initial stage of glycation resulting in the formation of a Schiff base and an Amadori product (Voziyan, and Hudson **2005).**

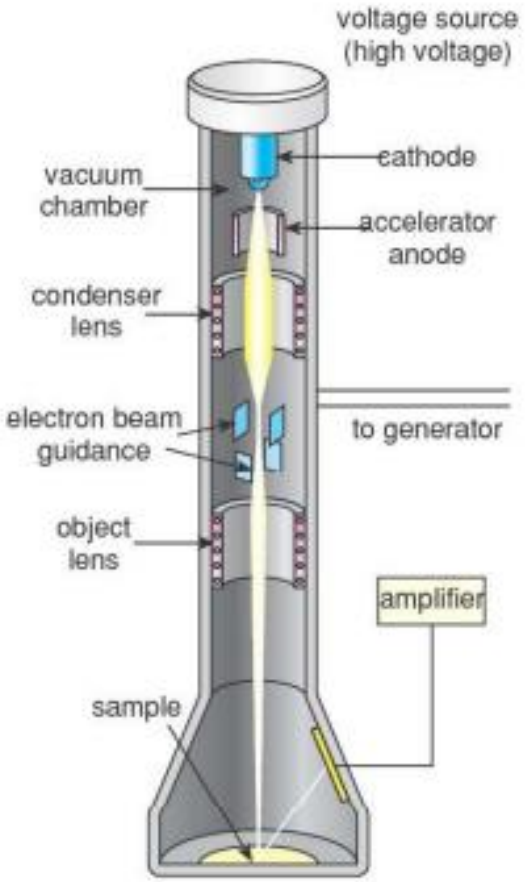


Matsuda Y, Miura J, Shimizu M, Aoki T, Kubo M, Fukushima S, Hashimoto M, Takeshige F, Araki T. Influence of Nonenzymatic Glycation in Dentinal Collagen on Dental Caries. J Dent Res. 2016 Dec;95(13):1528-1534.

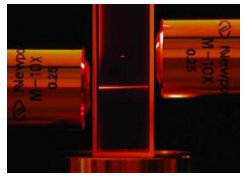
Methods

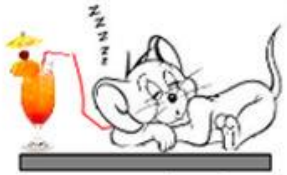
What techniques can help us answering scientific questions?

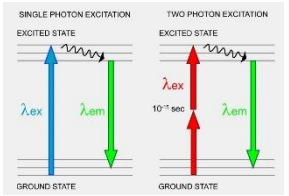
Scanning electron microscopy (SEM)



Two-photon microscopy







sample

objective

dicroic mirror (700 nm)

LG

green chanel
490-560 nm

XY szkenner

Pockels cella (intenzitás)

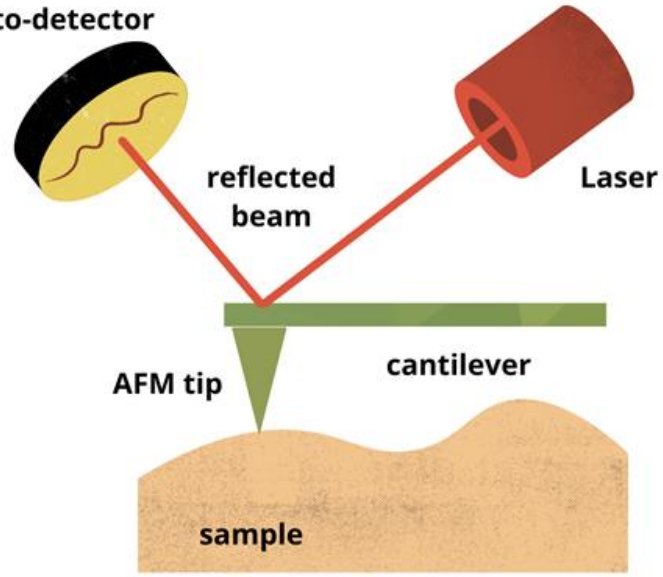
LR

red chanel
600-700 nm

MaiTai Deep Sea Laser

Tunable range: 700-1400 nm
Frequency: 80 MHz
Impulse lenght: 100 fs
Average power: 3 W

Atomic force microscopy (AFM)



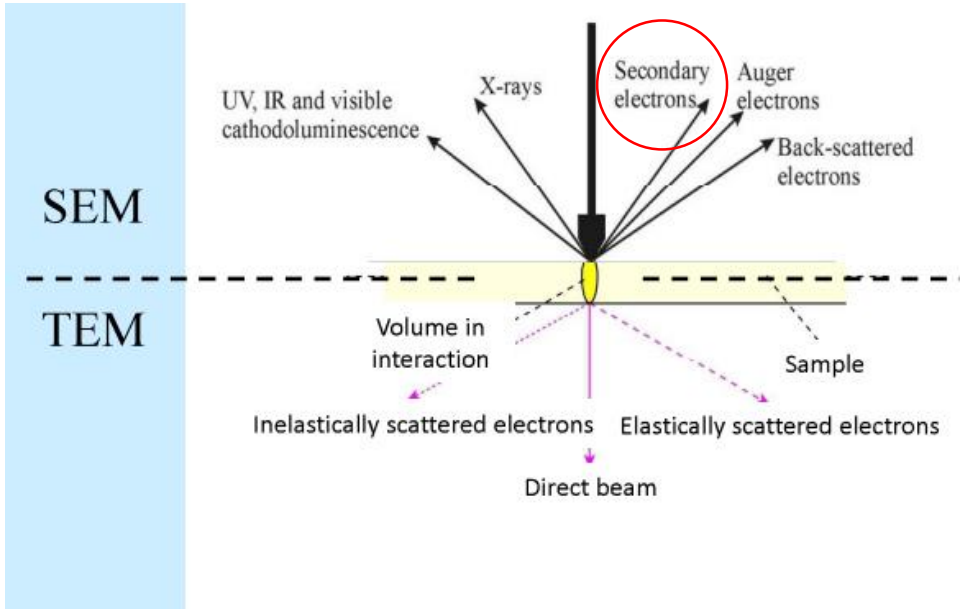
others…

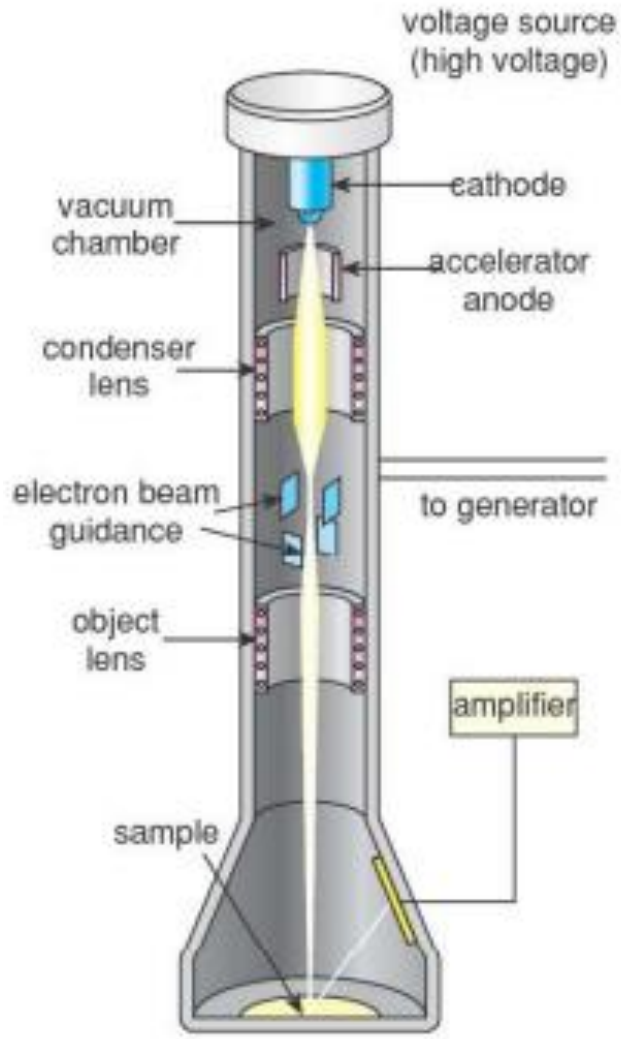
Scanning electron microscopy (SEM)

What can be examined?

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

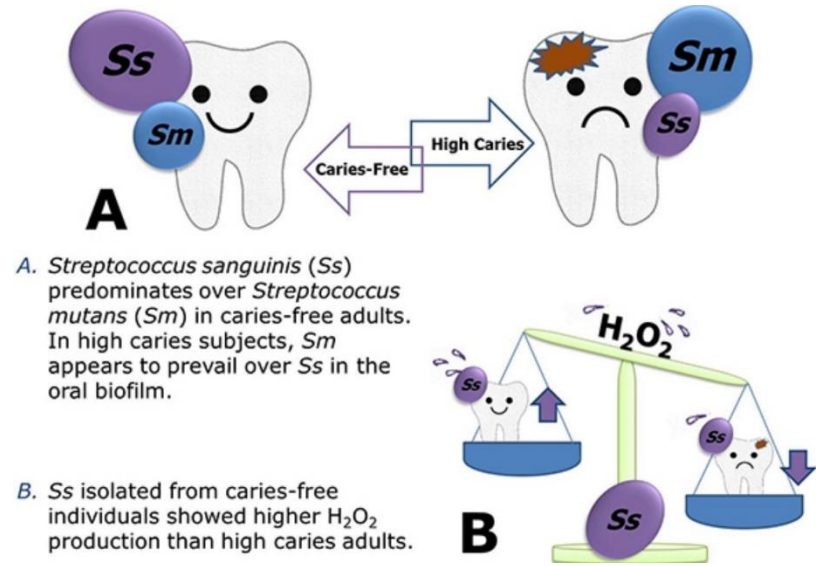
$$\lambda = \frac{h}{mv}$$





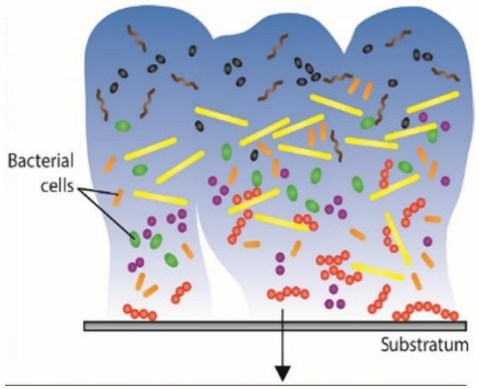
Structure and development of dental plaque

- Biofilm-mediated oral diseases: dental caries, periodontonal 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



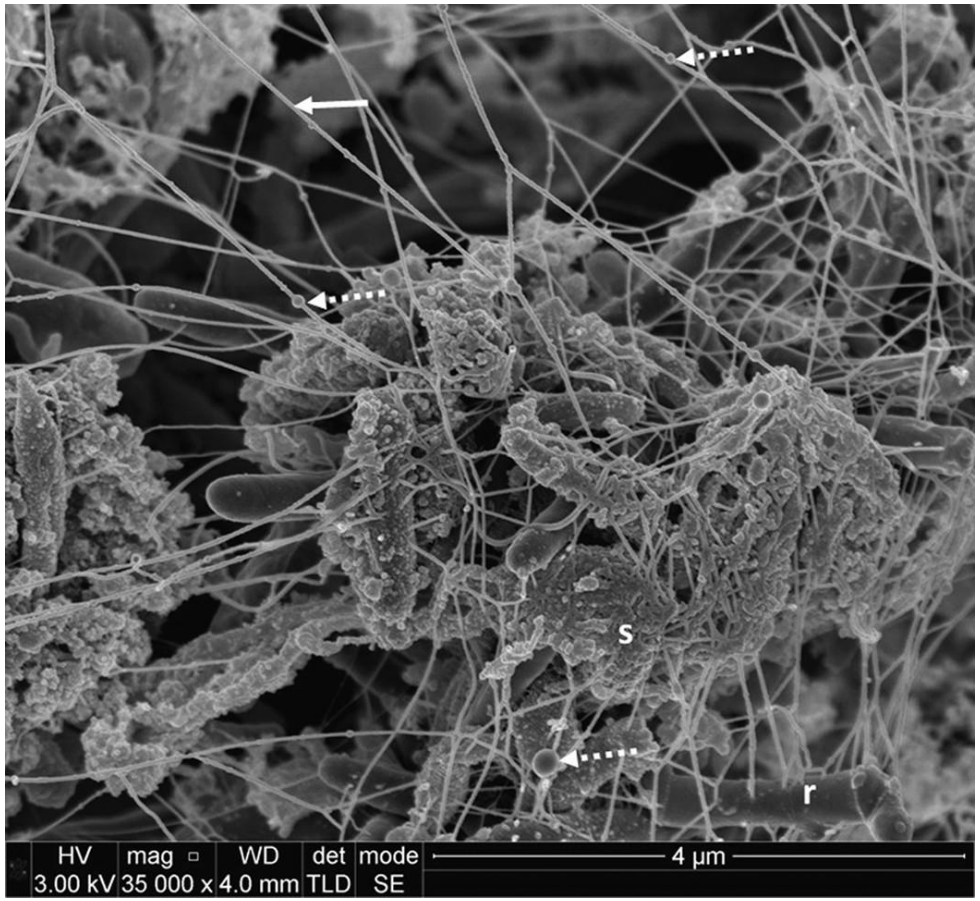
https://www.sciencedirect.com/science/article/pii/S0003996914002489

Biofilm matrix
Glucans, capsules, PNAG, LTA
eDNA
Amyloids, adhesins, enzymes, DNA binding proteins
Peptidoglycan fragments
S layers, adhesins
Lipids, LPS
Attachment of microbial cells
Biomechanical resistance
Restricts immune cell penetration
Quorum sensing
Protection, nutrient store
Gene pool

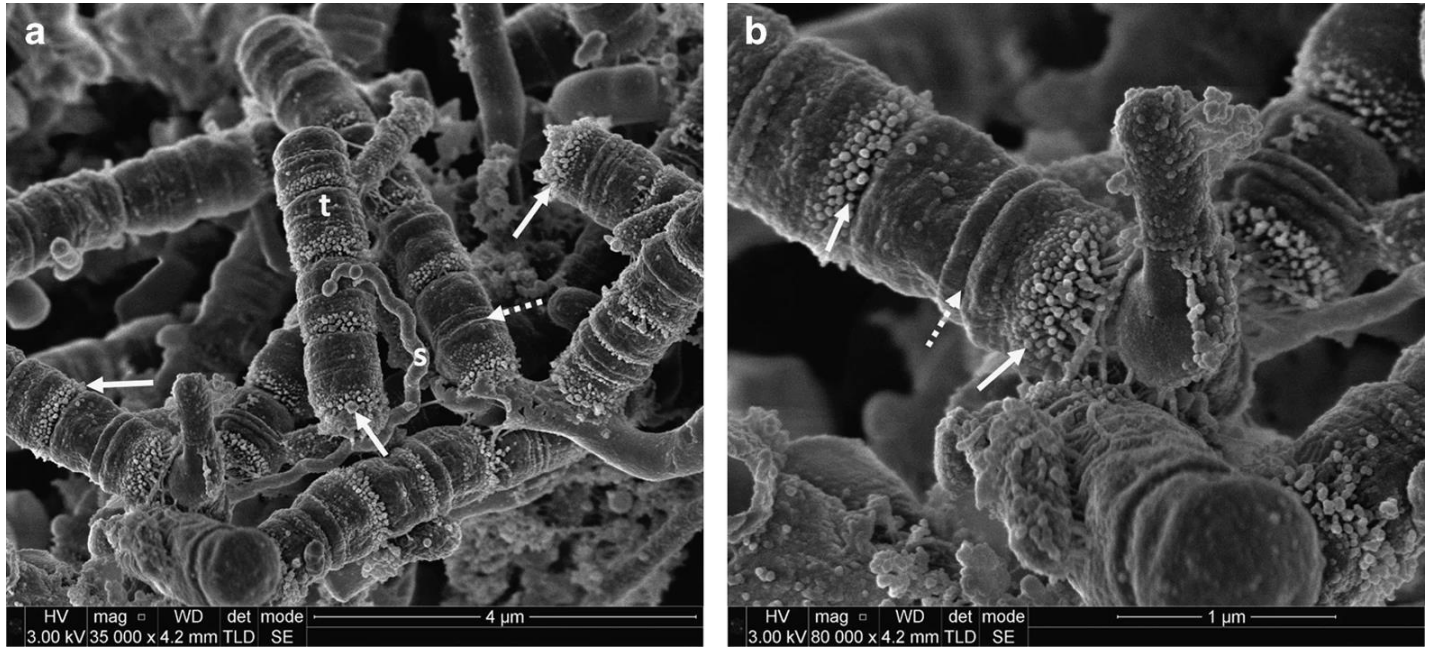


https://onlinelibrary.wiley.com/doi/full/10.1111/prd.12361

Ultrastructure of dental plaques



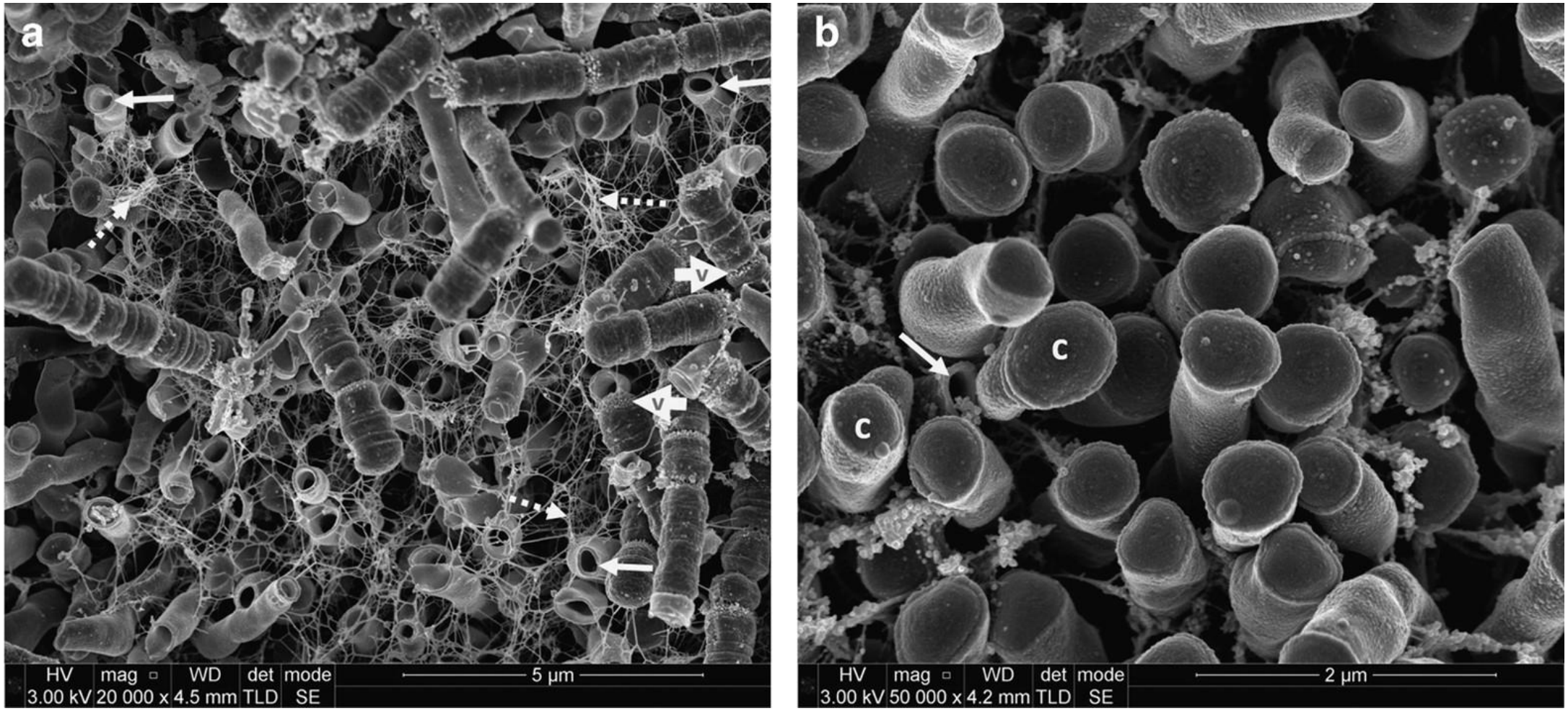
web of extracellular matrix material, rod-shaped cells



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

Holliday, R., Preshaw, P., Bowen, L. et al. The ultrastructure of subgingival dental plaque, revealed by high-resolution field emission scanning electron microscopy. BDJ Open 1, 15003 (2015)

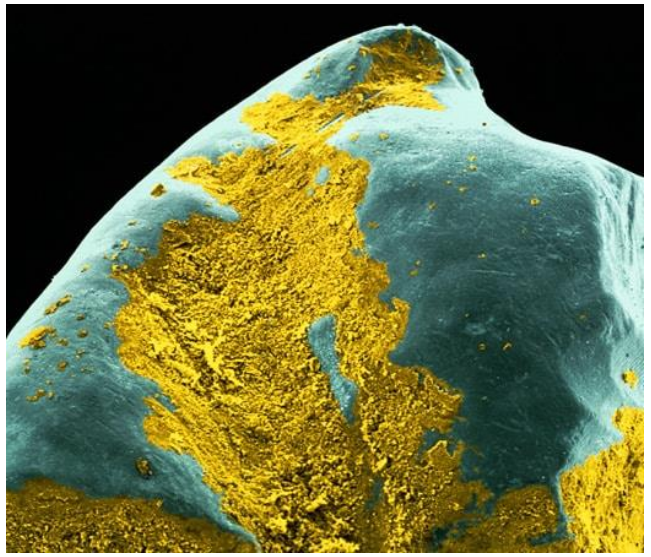
Ultrastructure of dental plaques II



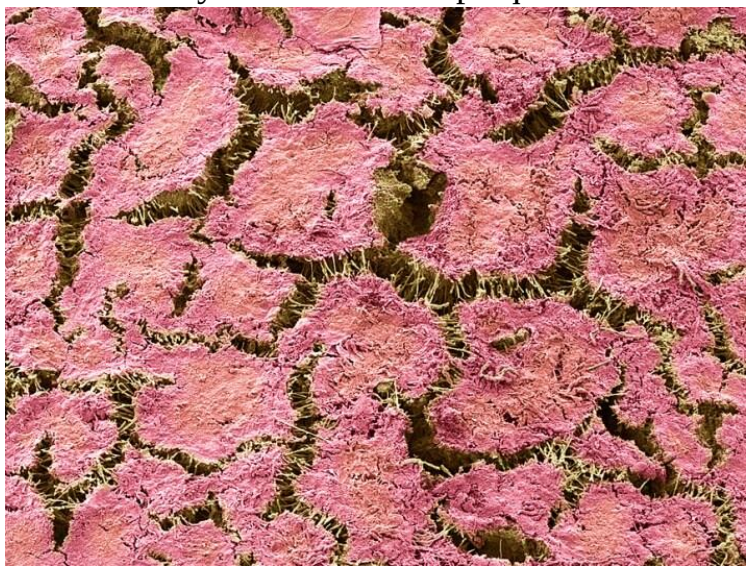
arrow: open tubules, broken arrow: extensive web of extracellular strands, short rod-shaped microorganisms,
v: vesicles, c: cells

Holliday, R., Preshaw, P., Bowen, L. et al. The ultrastructure of subgingival dental plaque, revealed by high-resolution field emission scanning electron microscopy. BDJ Open 1, 15003 (2015)

Ultrastructure of dental plaques III

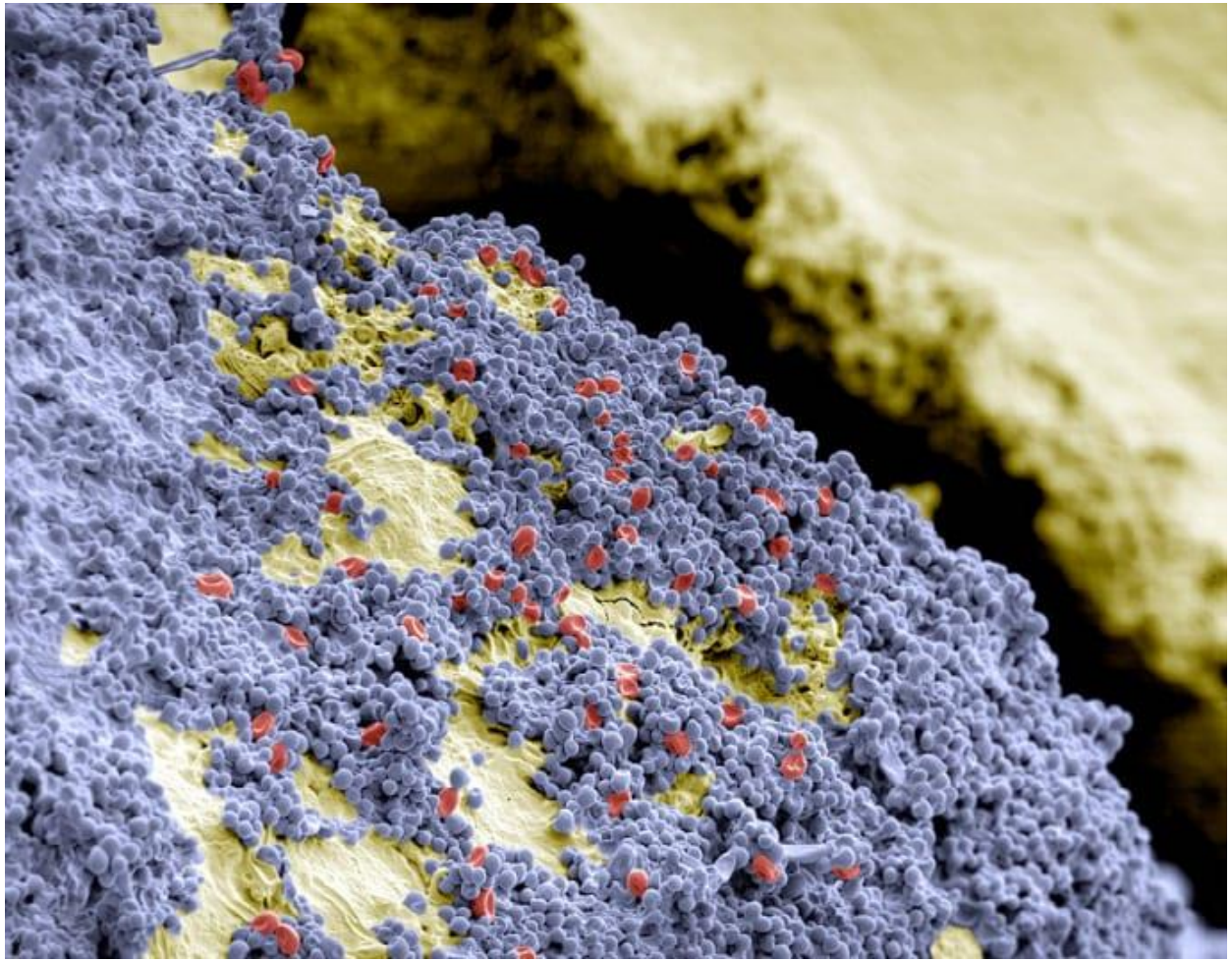


yellow: bacterial plaque



Dental plaque, biofilm (400x)

Blue: colony of coccid bacteria, red: RBC



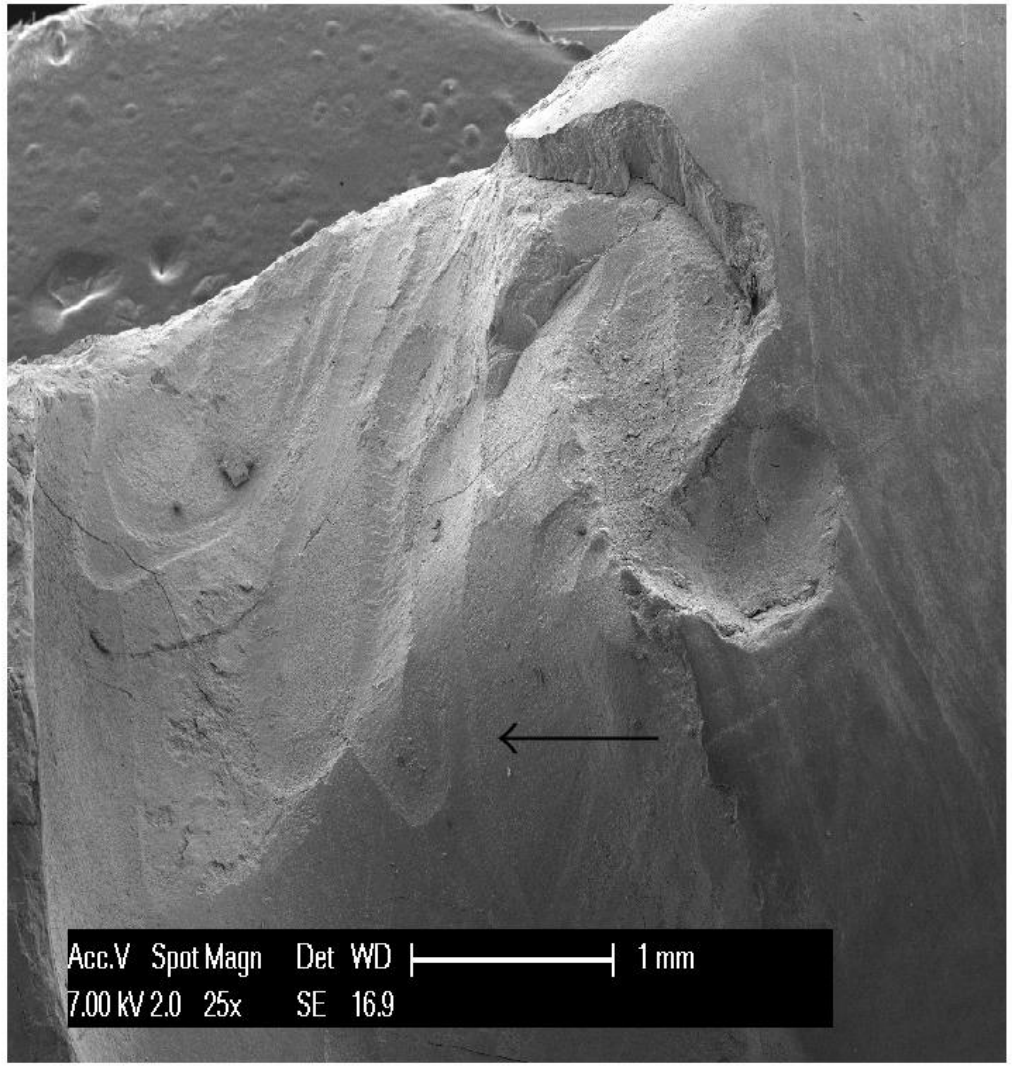
https://www.telegraph.co.uk/news/picturegalleries/howaboutthat/11067916/Plaque-attack-Close-up-images-of-teeth-reveal-what-lives-in-your-mouth.html

Types of dental wear

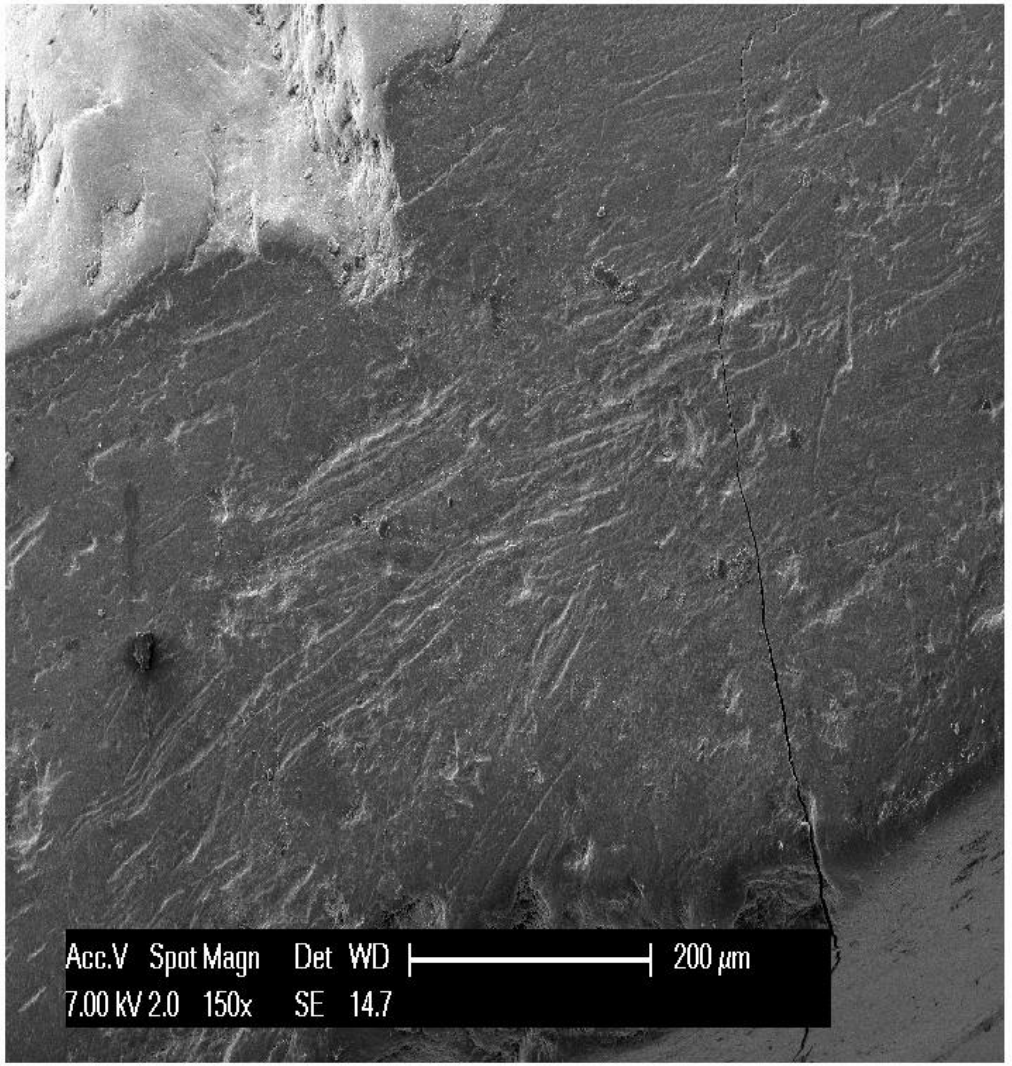
loss of mineralized tissue unrelated to bacterial action

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 (mechancial)**: when the tooth is subjected to extreme stress and fatigue

Abfraction and attrition of enamel



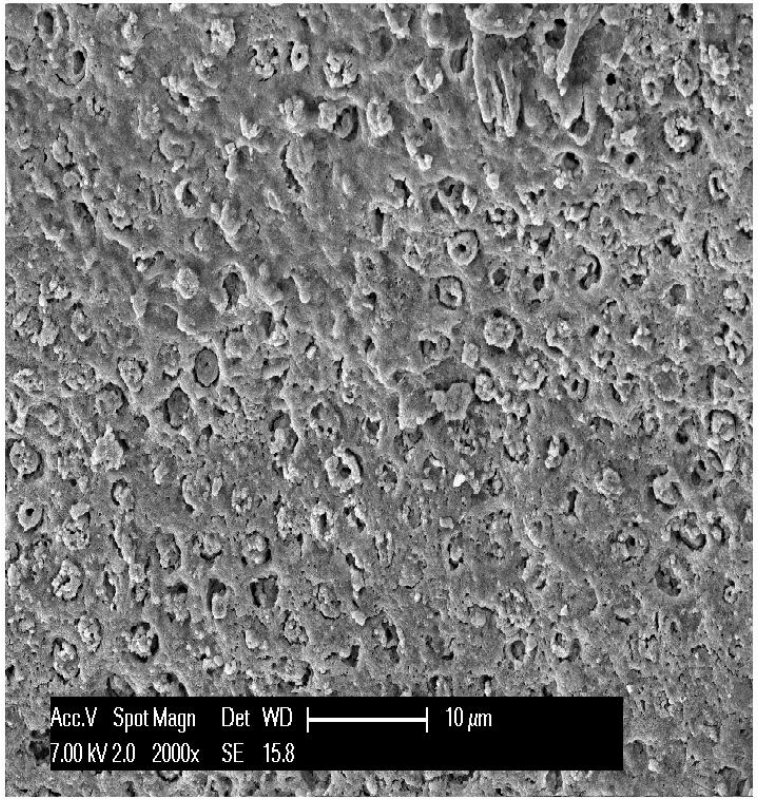
enamel abfraction: multiple cavities, partially overlapping furrows



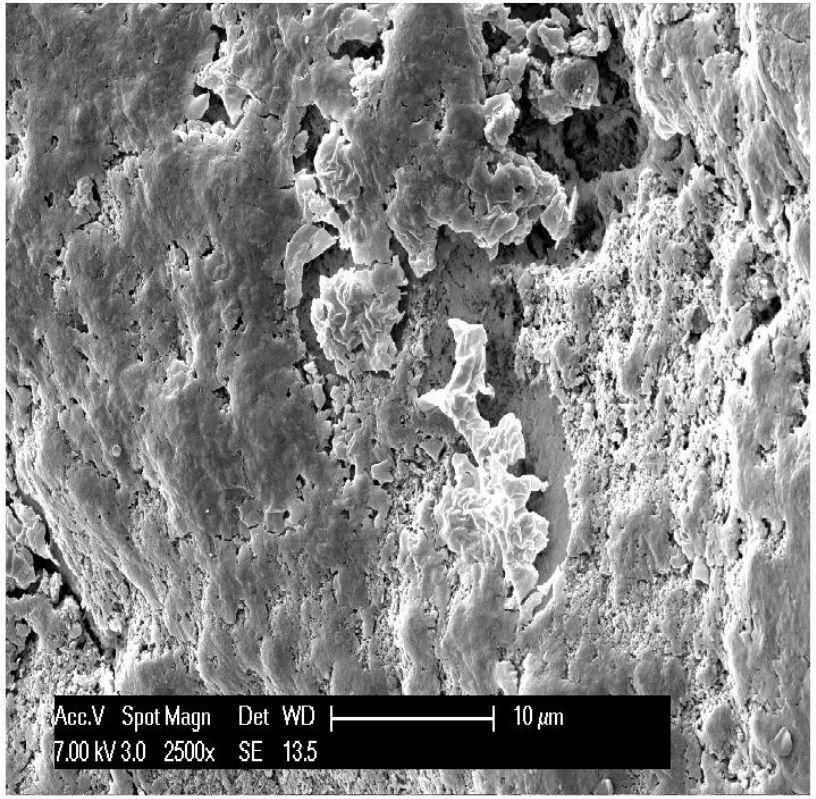
enamel attrition: scratches, stripes, and striations

Levrini L, Di Benedetto G, Raspanti M. Dental wear: a scanning electron microscope study. Biomed Res Int. 2014

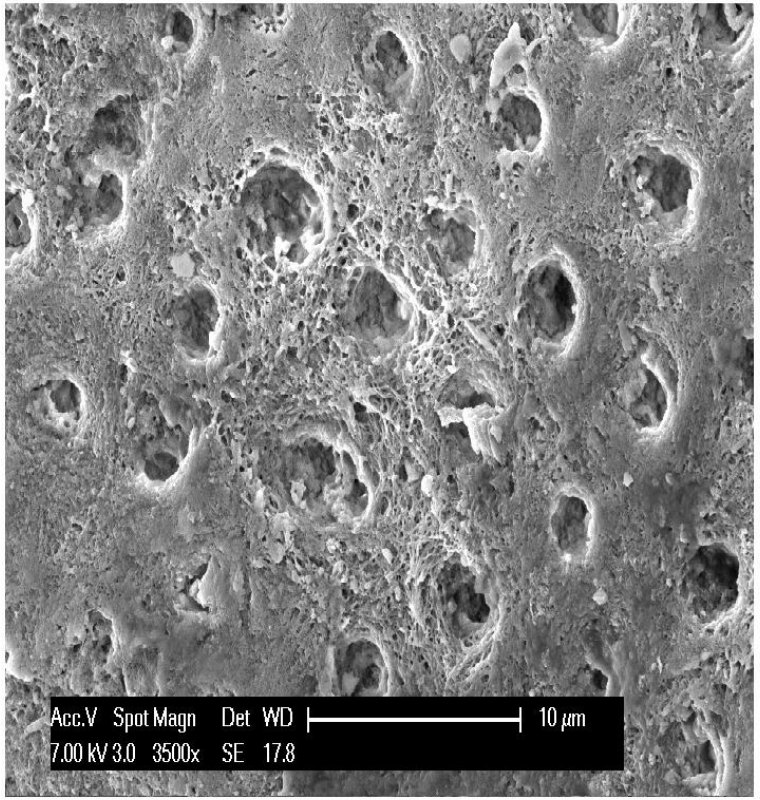
Lesions of dentin



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.

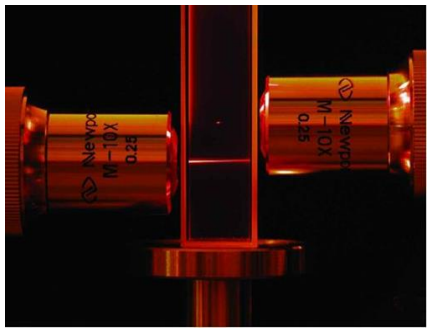


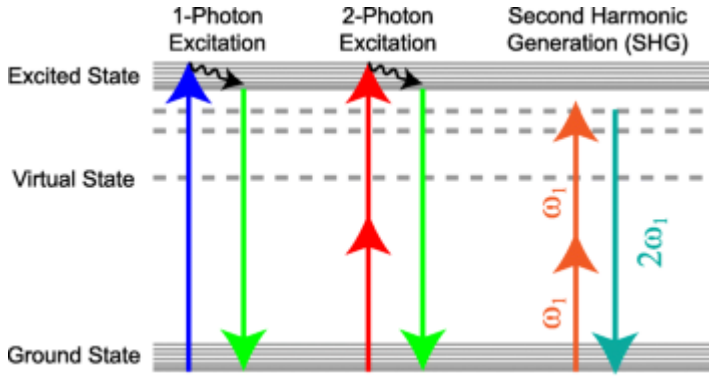
In erosion lesions, the tubules have rounded openings; the collagen matrix between them is eroded and demineralized.

Levrini L, Di Benedetto G, Raspanti M. Dental wear: a scanning electron microscope study. Biomed Res Int. 2014

Two-photon microscopy

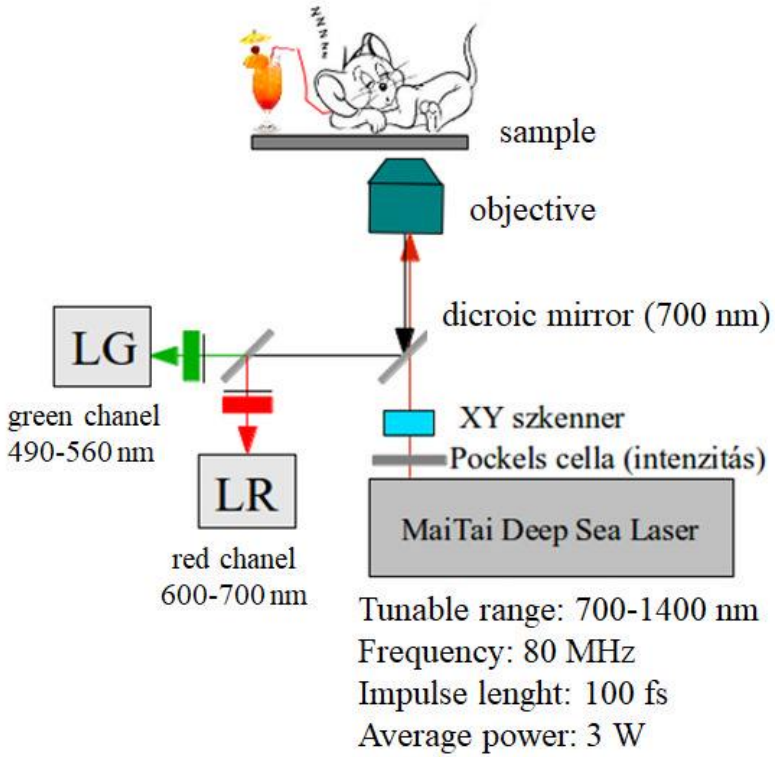
What can be examined?





1. autofluorescence and second harmonic generated signal from organic components of dentin (e.g. collagen) under normal and pathological conditions

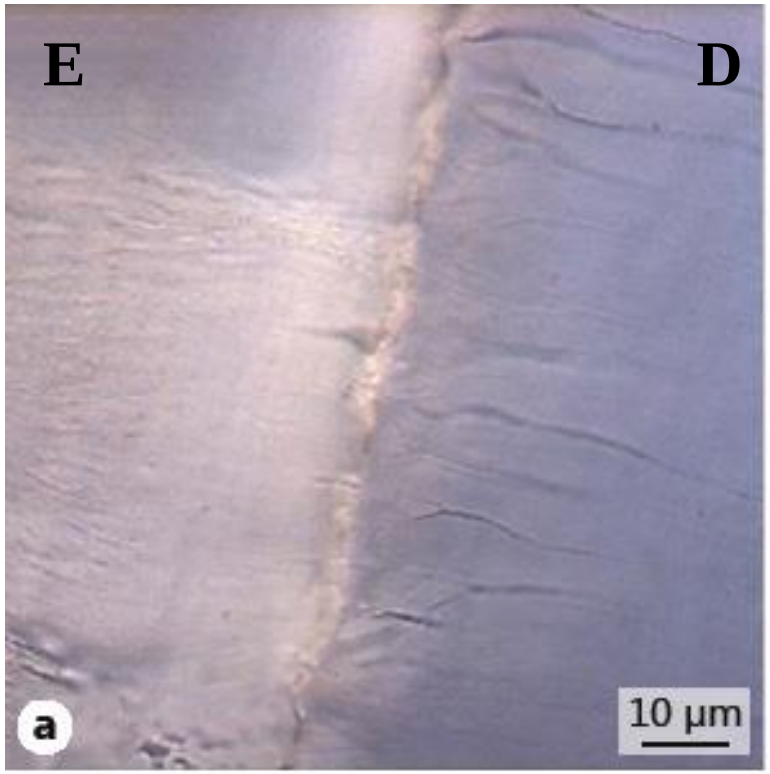
2. Structure, orientation and periodicity of collagen fibers



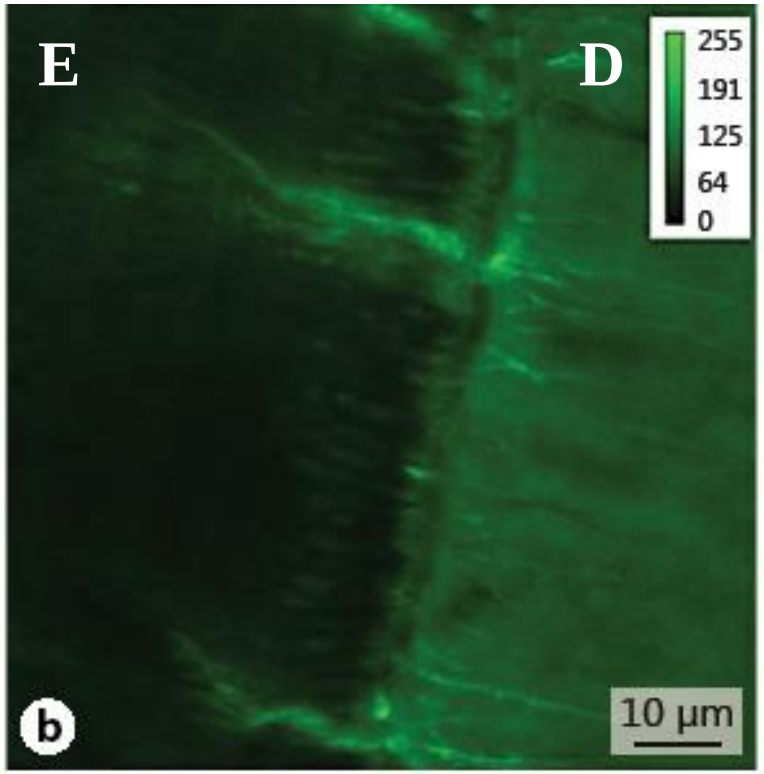
Second-harmonic generation (SHG, also called frequency doubling) is a nonlinear optical process in which two photons with the same frequency interact with a nonlinear material, are "combined", and generate a new photon with twice the energy of the initial photons (equivalently, twice the frequency and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

Normal dentin-enamel junction (DEJ)

Bright-field

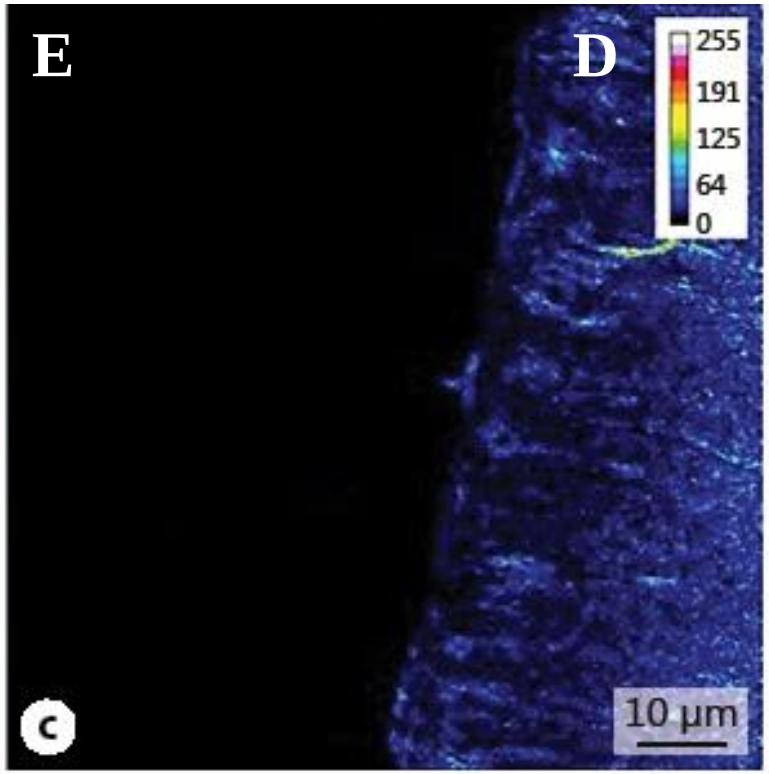


2PEF



autofluorescence – organic components (E + D)

SHG

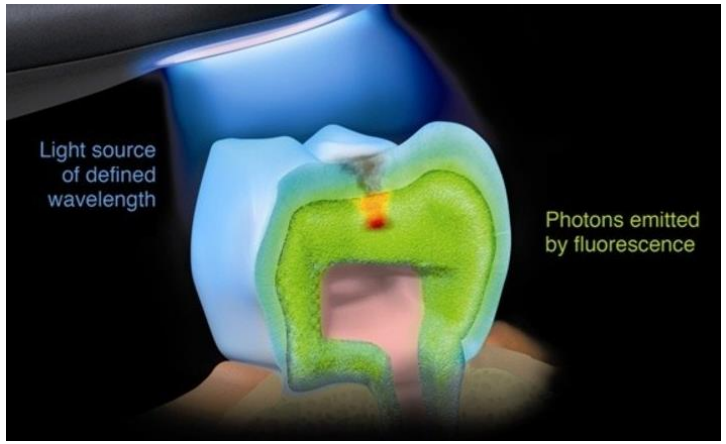


SHG signal only in dentin – presence of collagen

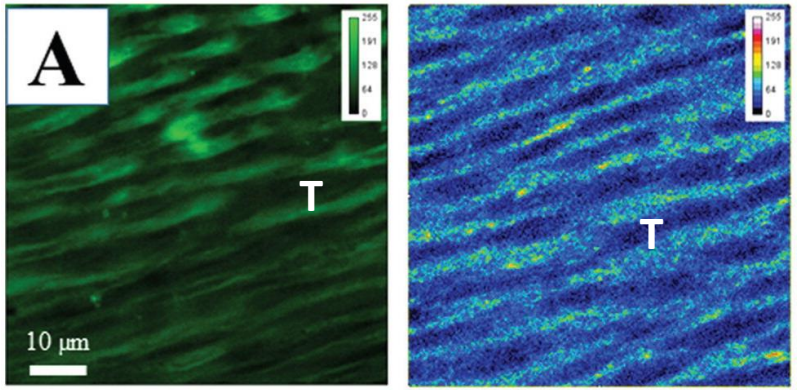
https://pubmed.ncbi.nlm.nih.gov/29510396/

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

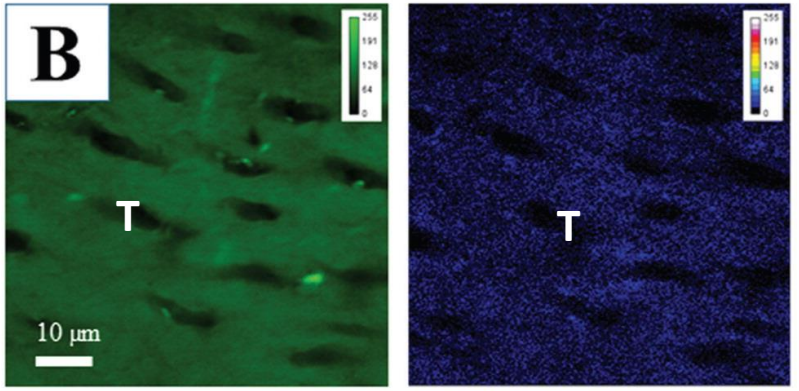
SoproLife camera – 450 nm



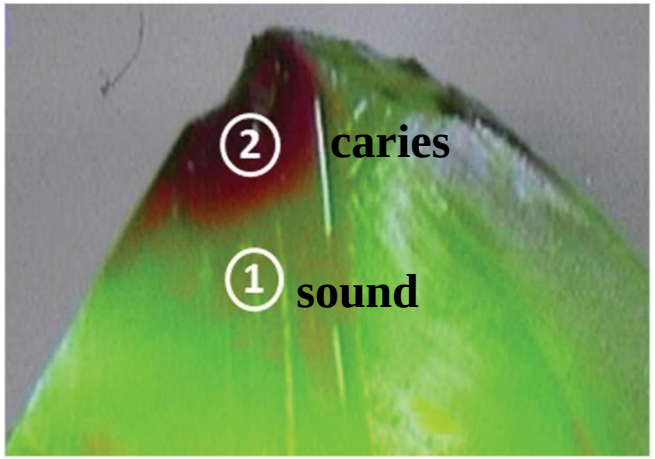
sound dentin

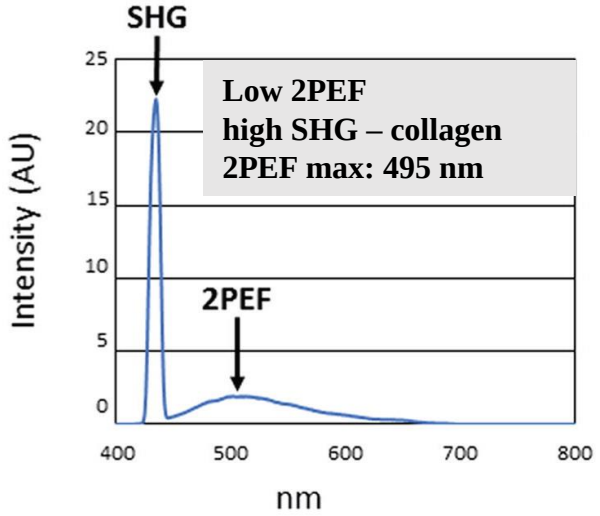


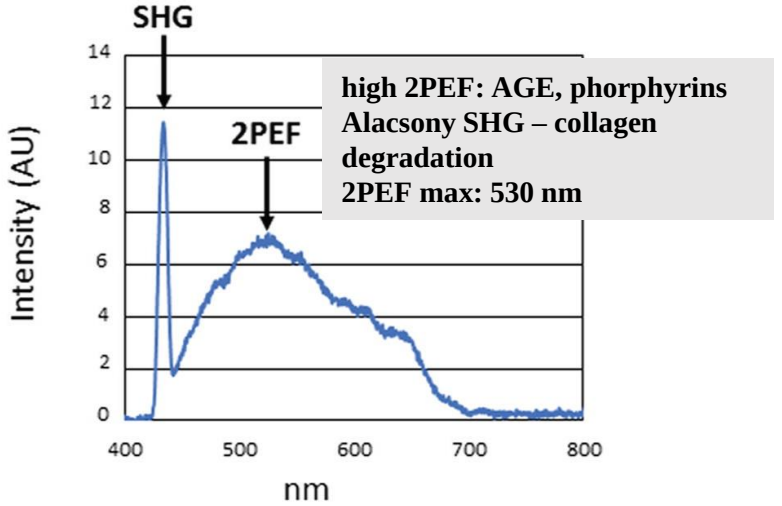
caries dentin



T: tubulus

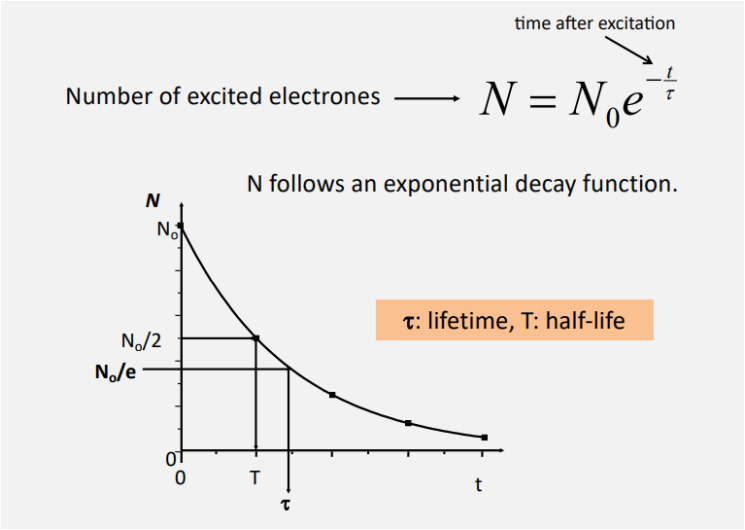






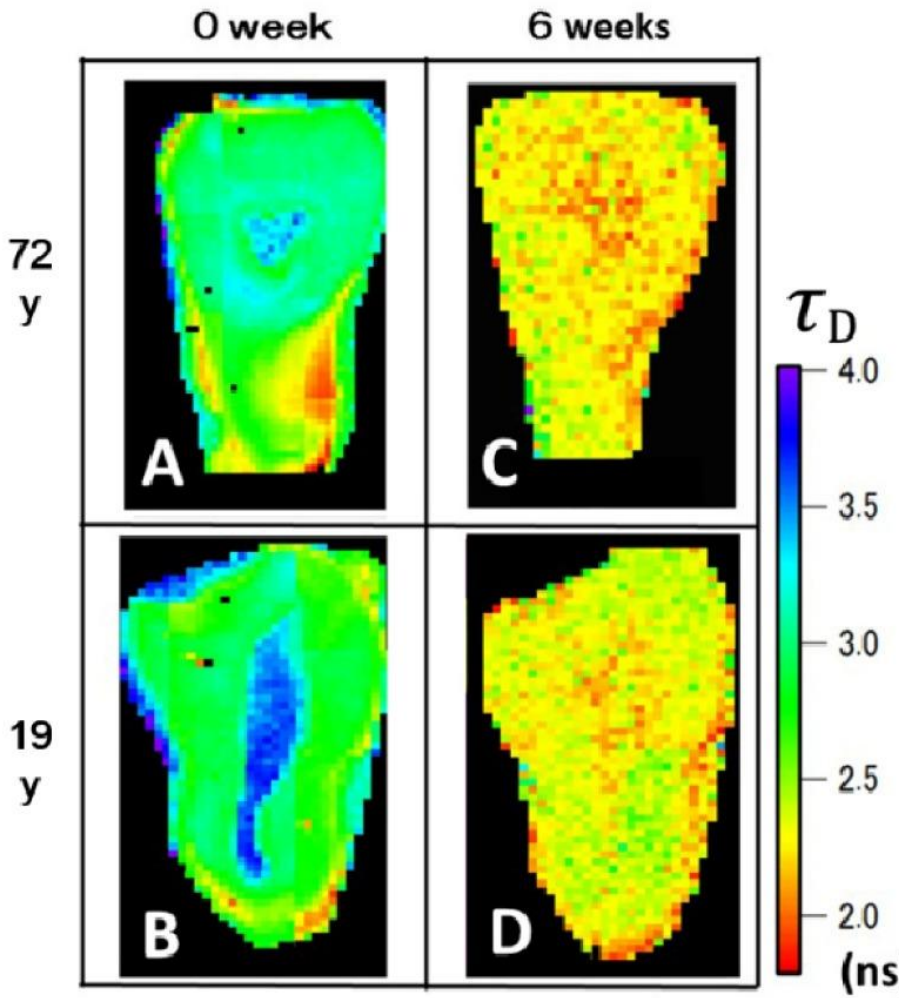
Terrer E, et al. 2016. Laboratory studies of nonlinear optical signals for caries detection. J Dent Res. 95(5):574–579.

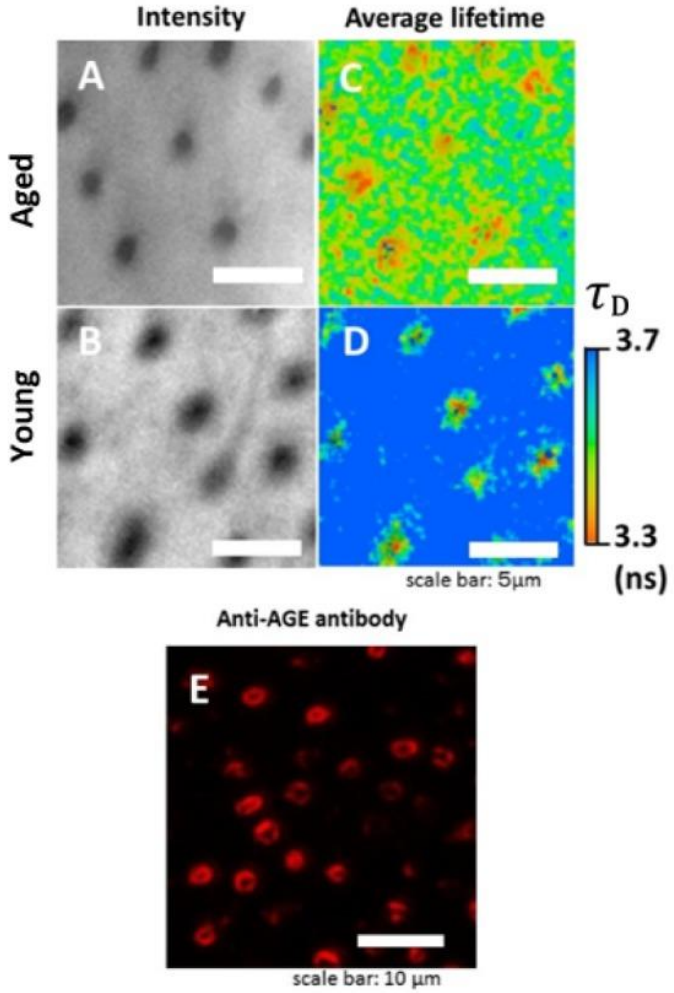
Decrease in fluorescence lifetime of dentin by ageing/glycation



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).

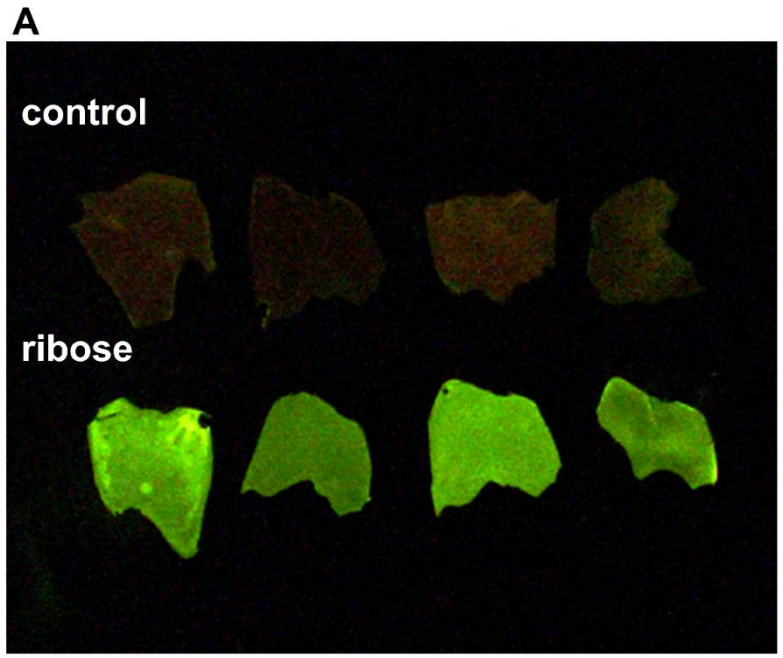




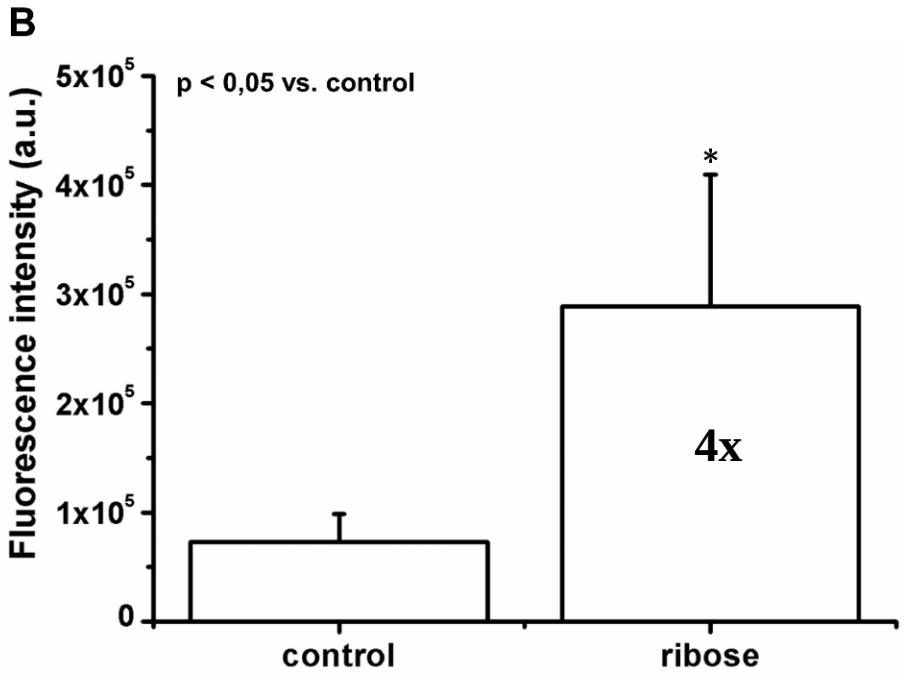
Fukushima S et. al. 2015. Decrease in fluorescence lifetime by glycation of collagen and its application in determining advanced glycation endproducts in human dentin. Biomed Opt Express. 6(5):1844–1856.

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

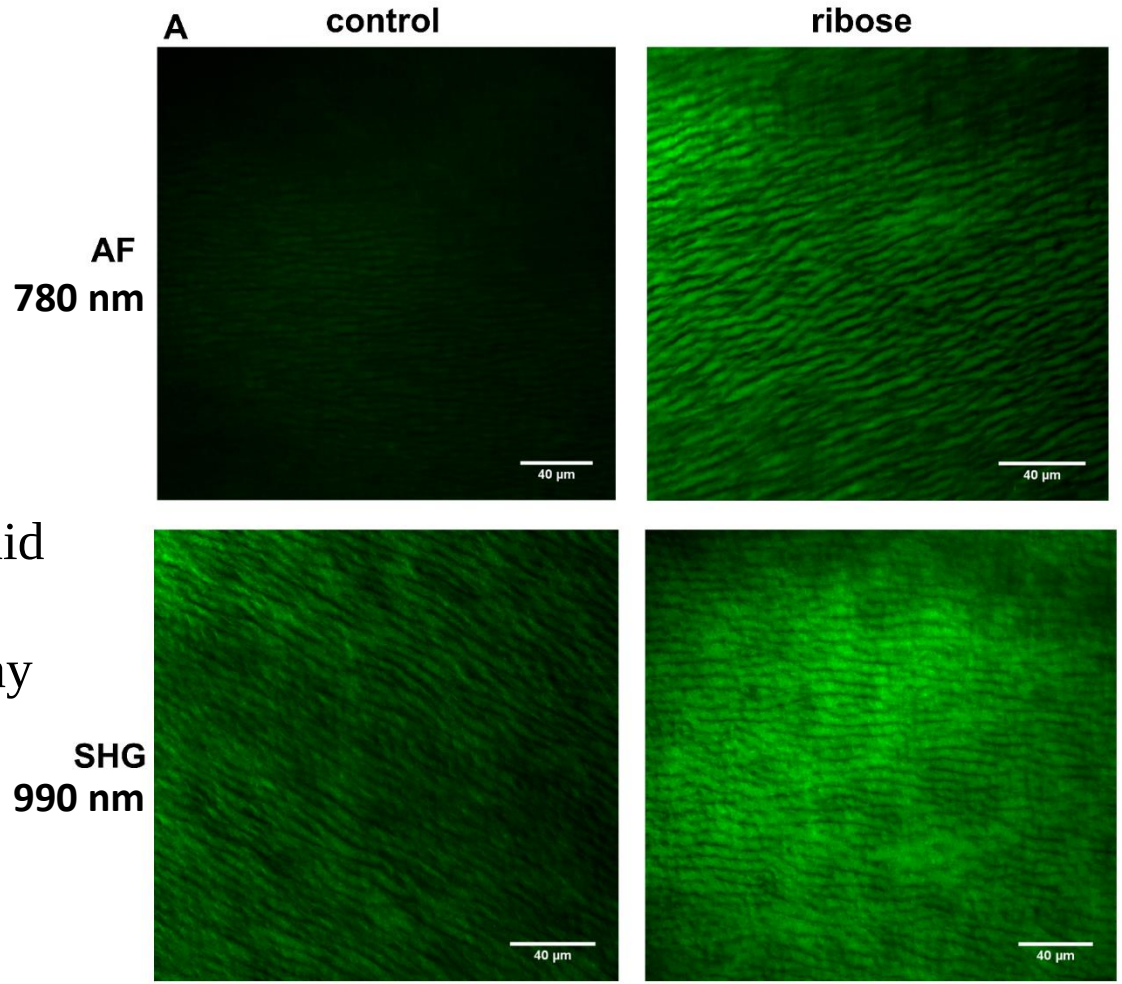


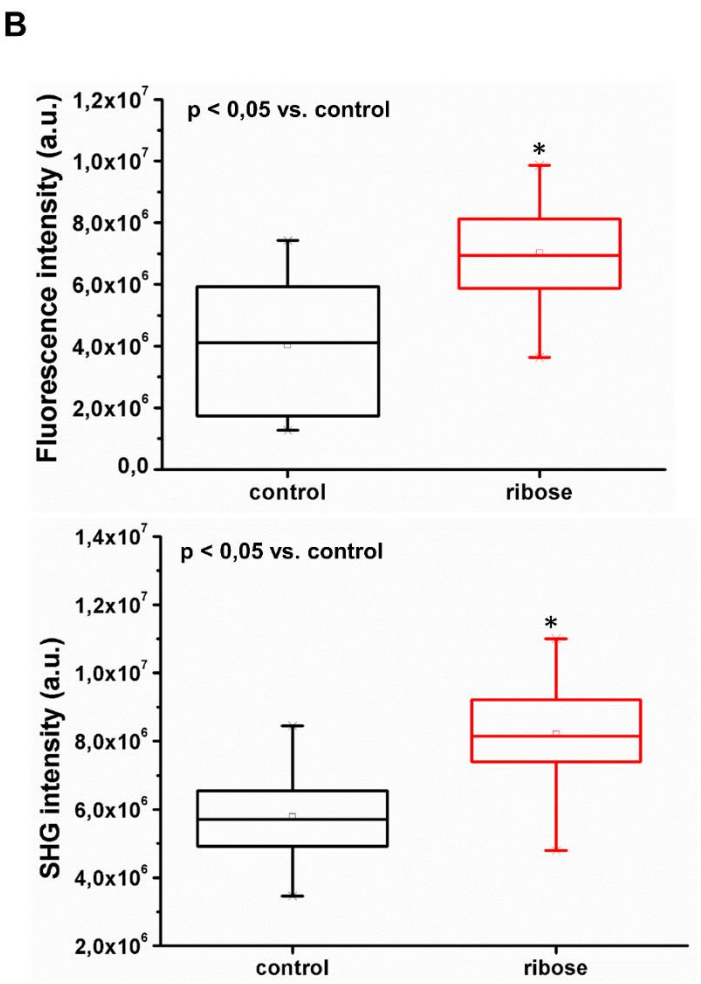
Haluszka D, Aminmansour S, Tóth P, Aminmansour S, Kellermayer M. Nanomechanical and Nonlinear Optical Properties of Glycated Dental Collagen. J Dent Res. 2022

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

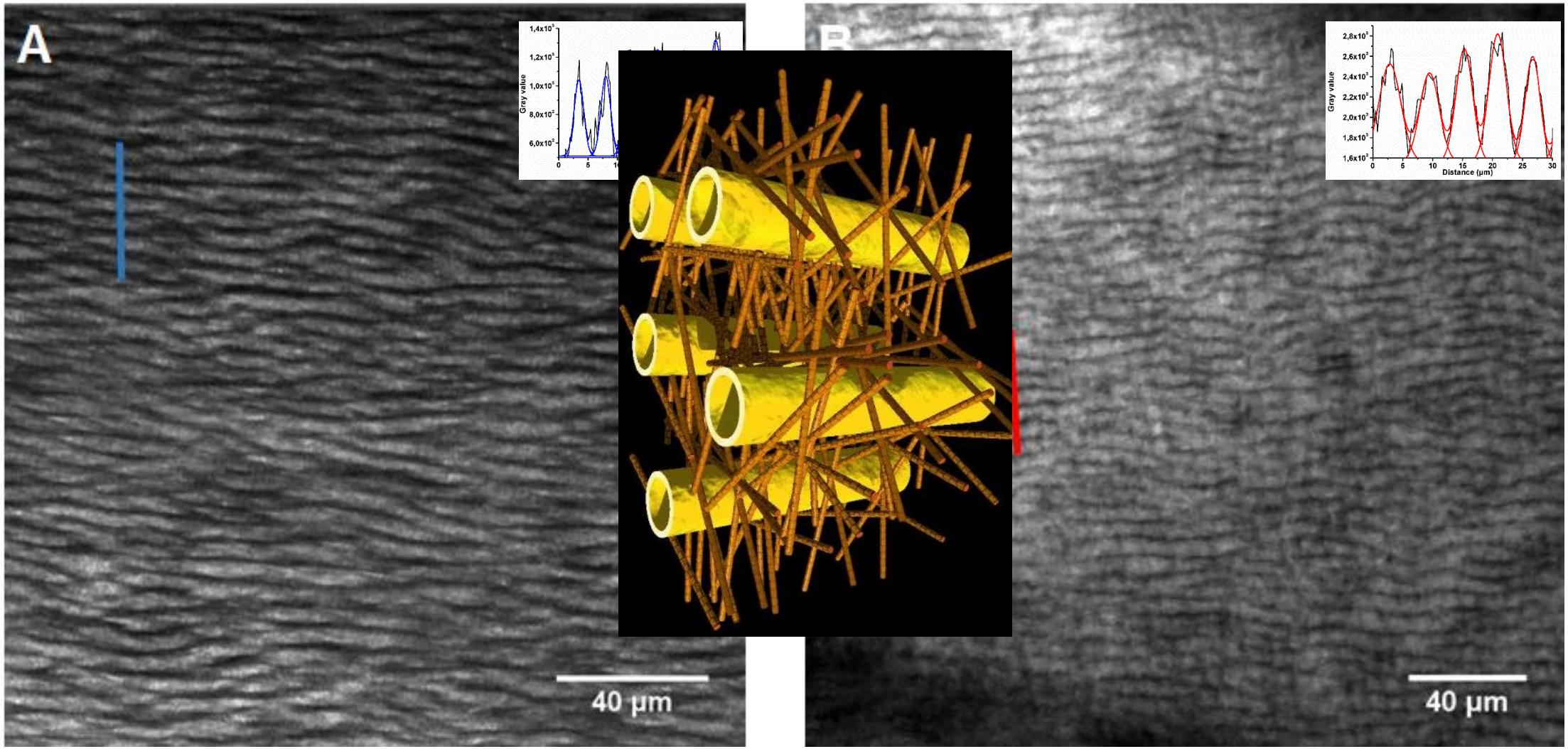




Haluszka D, Aminmansour S, Tóth P, Aminmansour S, Kellermayer M. Nanomechanical and Nonlinear Optical Properties of Glycated Dental Collagen. J Dent Res. 2022

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

SHG images



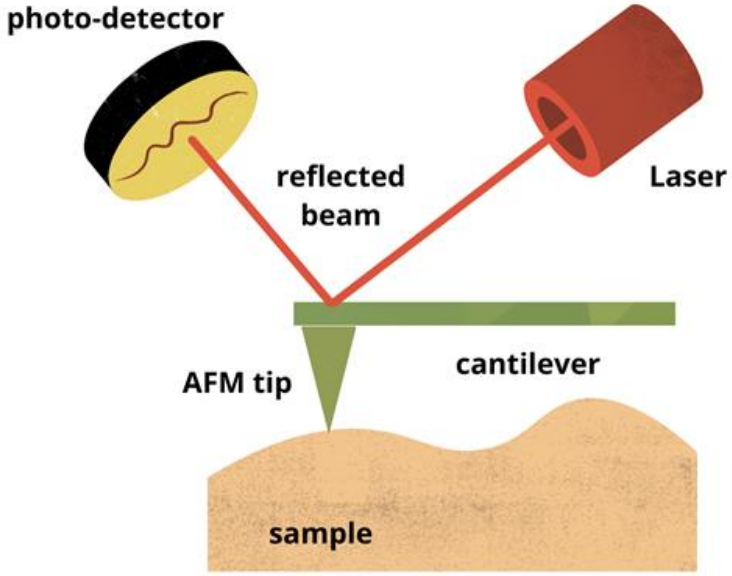
Haluszka D, Aminmansour S, Tóth P, Aminmansour S, Kellermayer M. Nanomechanical and Nonlinear Optical Properties of Glycated Dental Collagen. J Dent Res. 2022

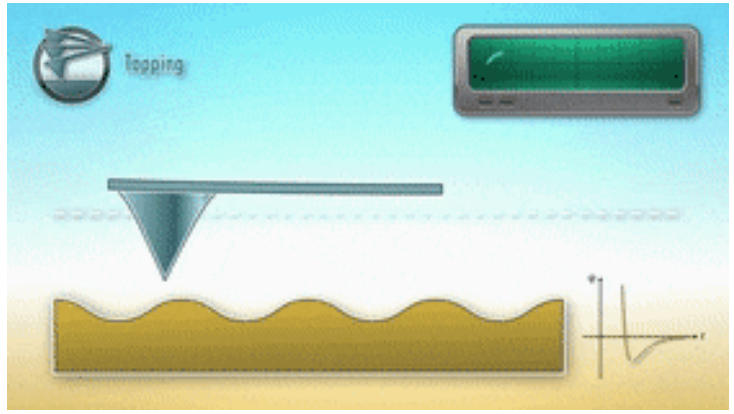
Atomic force microscopy (AFM)

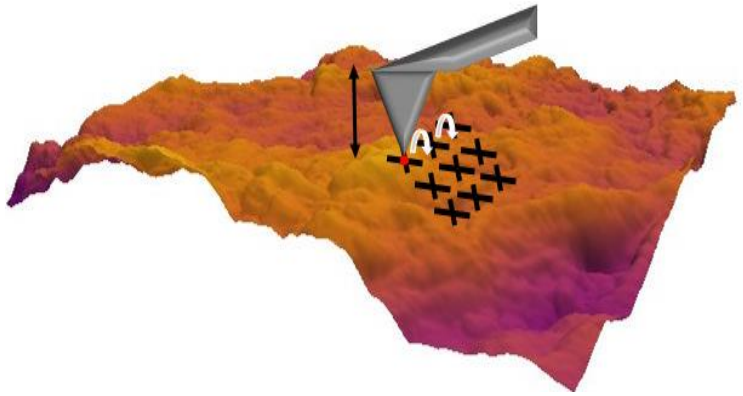
What can be examined?

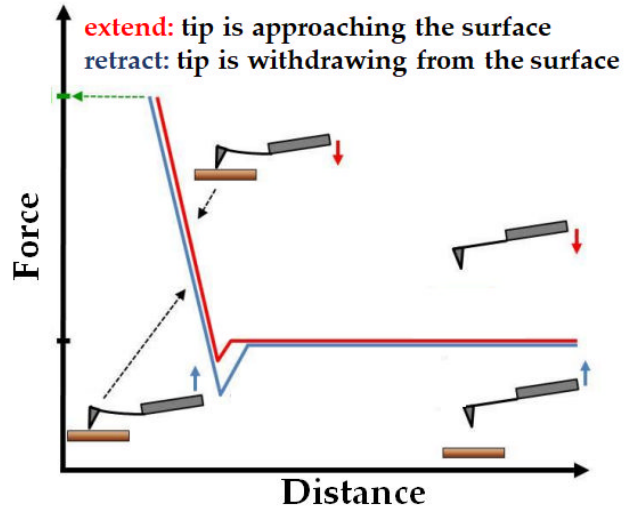
1. Topography: structure of surfaces, roughness (e.g. effects of surface treatments)

2. Mechanics: Young' modulus of demineralized dentinal collagen (e.g. diabetes)



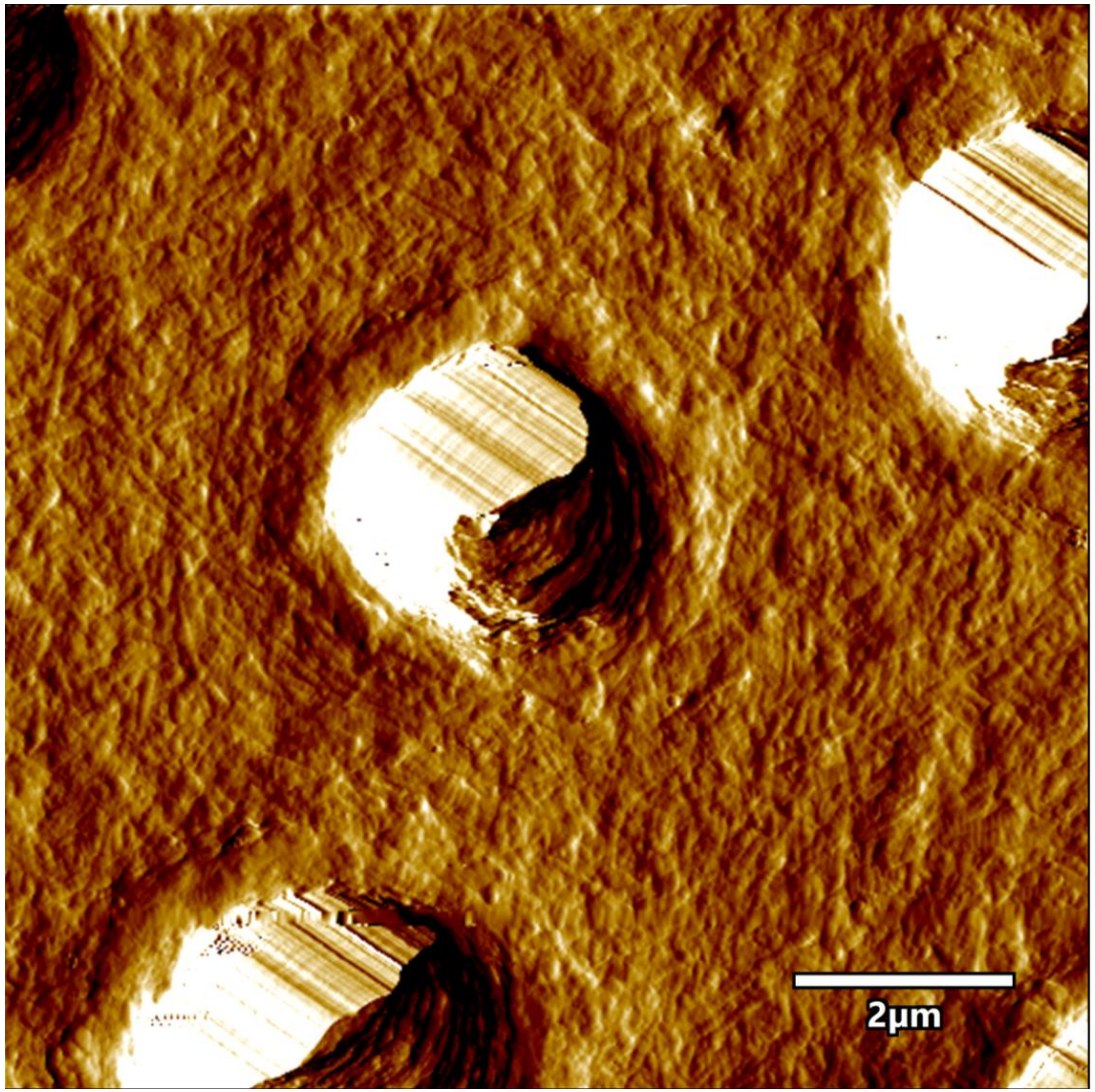




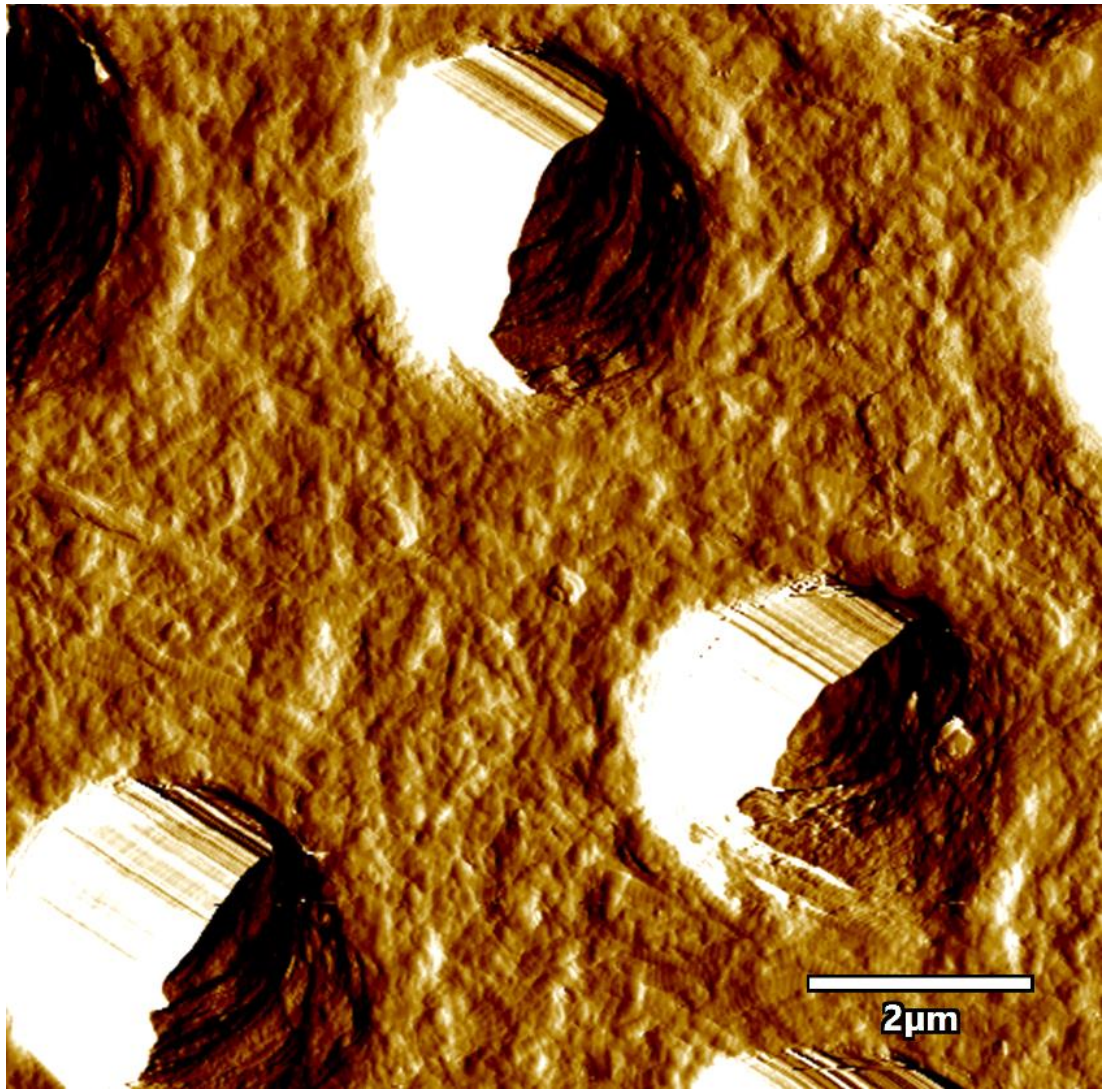


Glycation increased the roughness of intertubular dentin

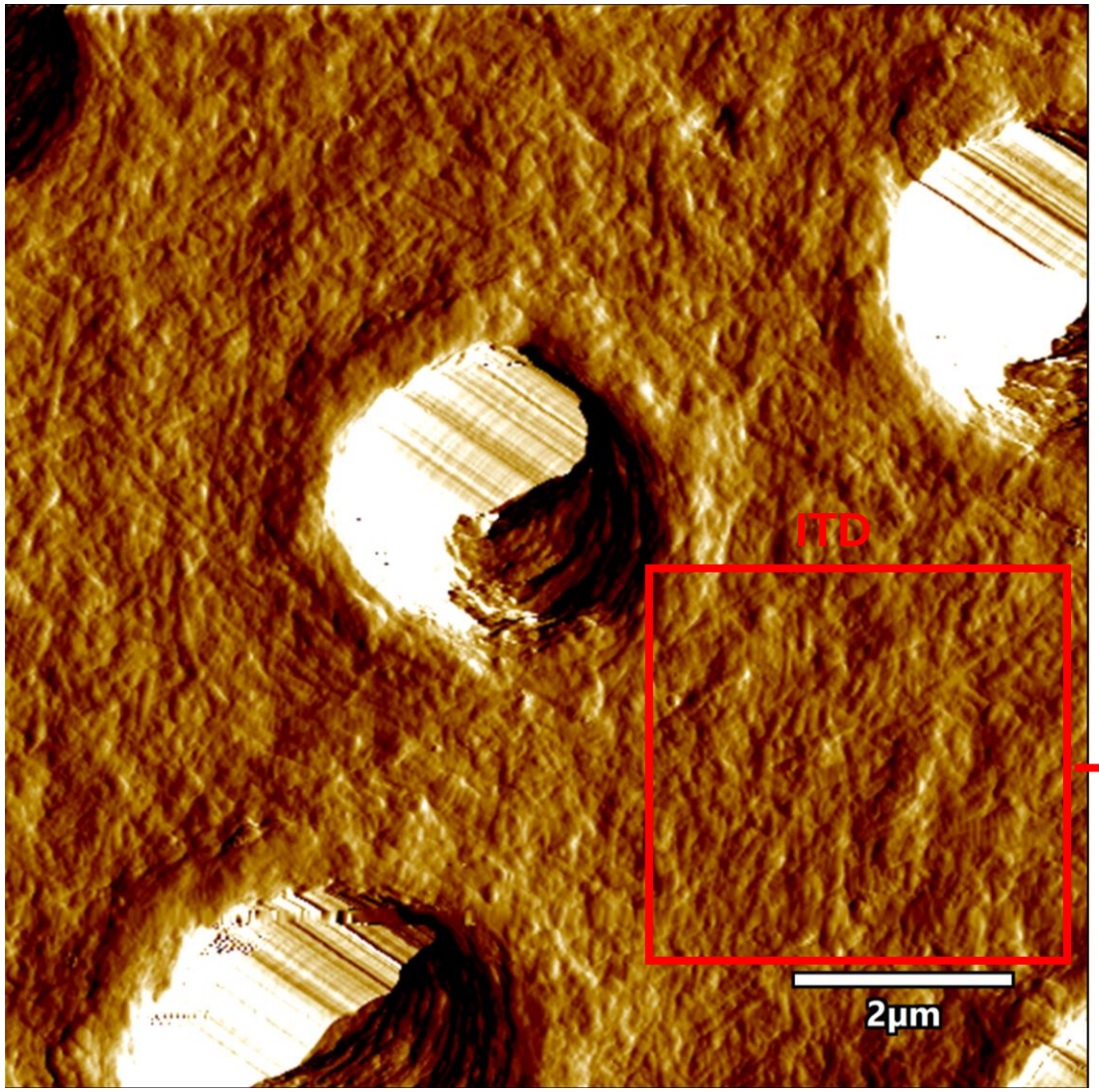
control

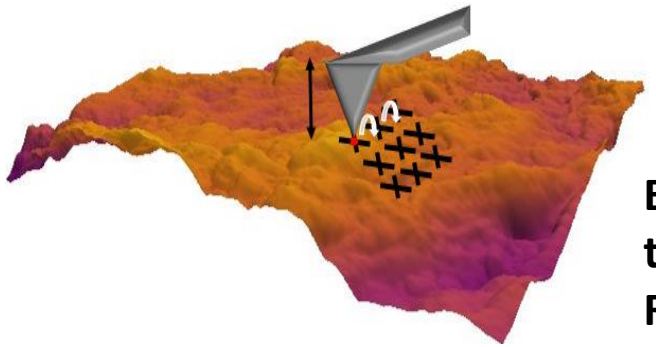


ribose



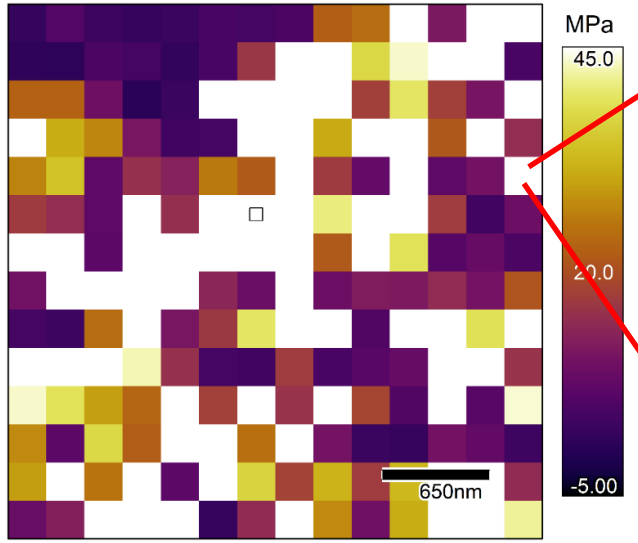
Force curve – force map

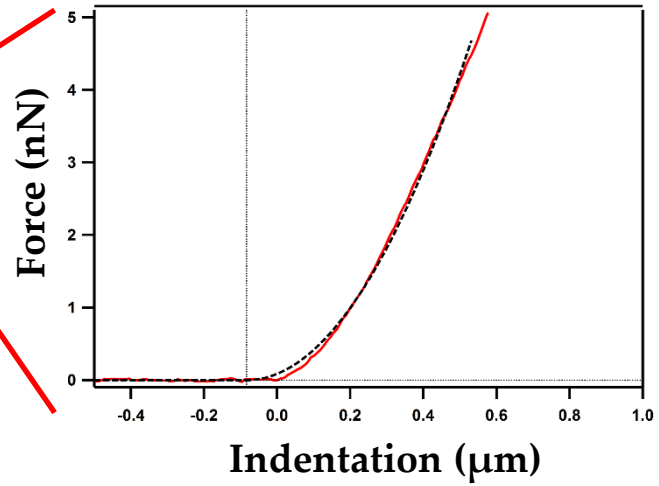




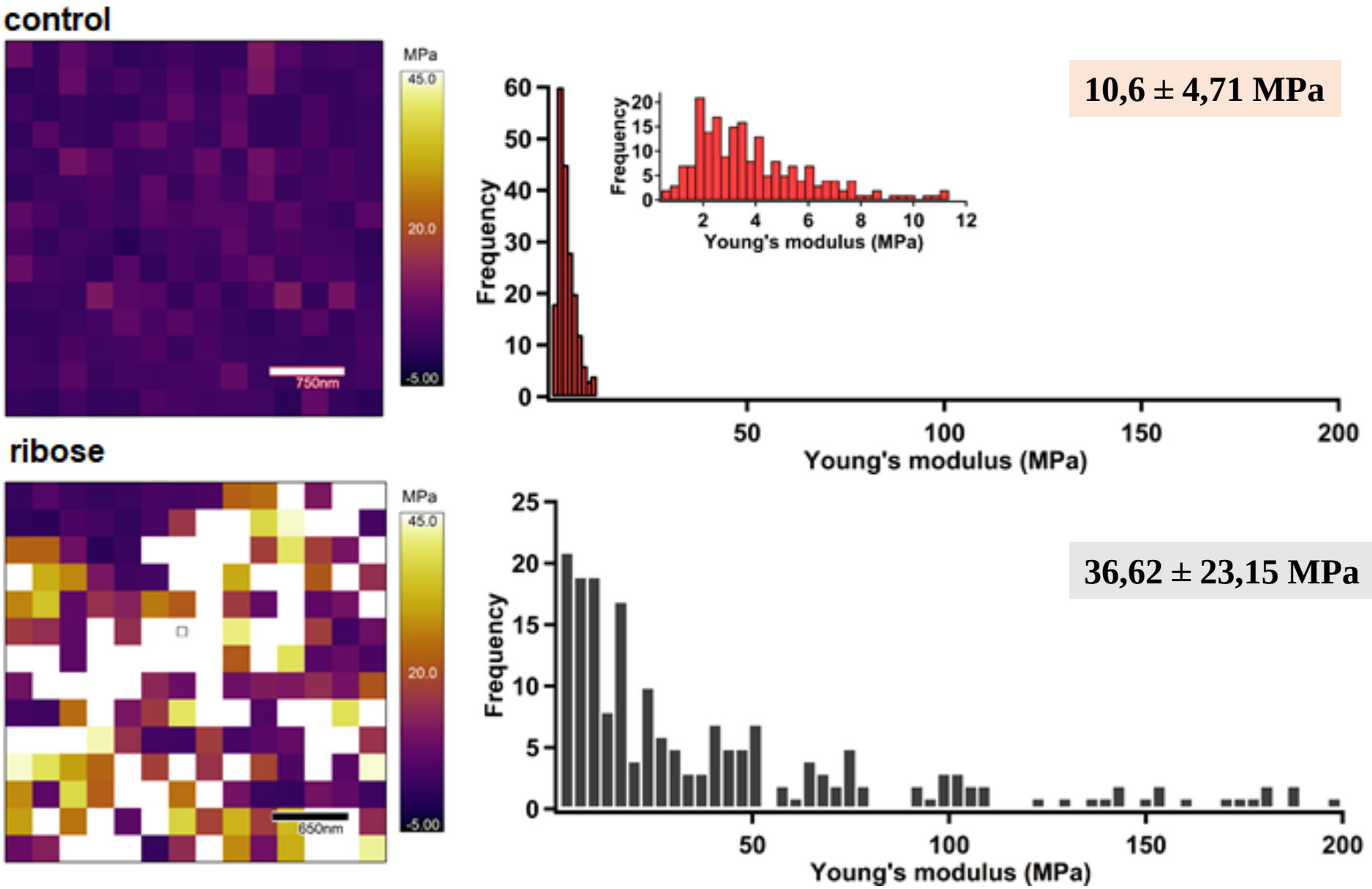
$$F = \frac{4}{3} E^* R^{1/2} d^{3/2}$$

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



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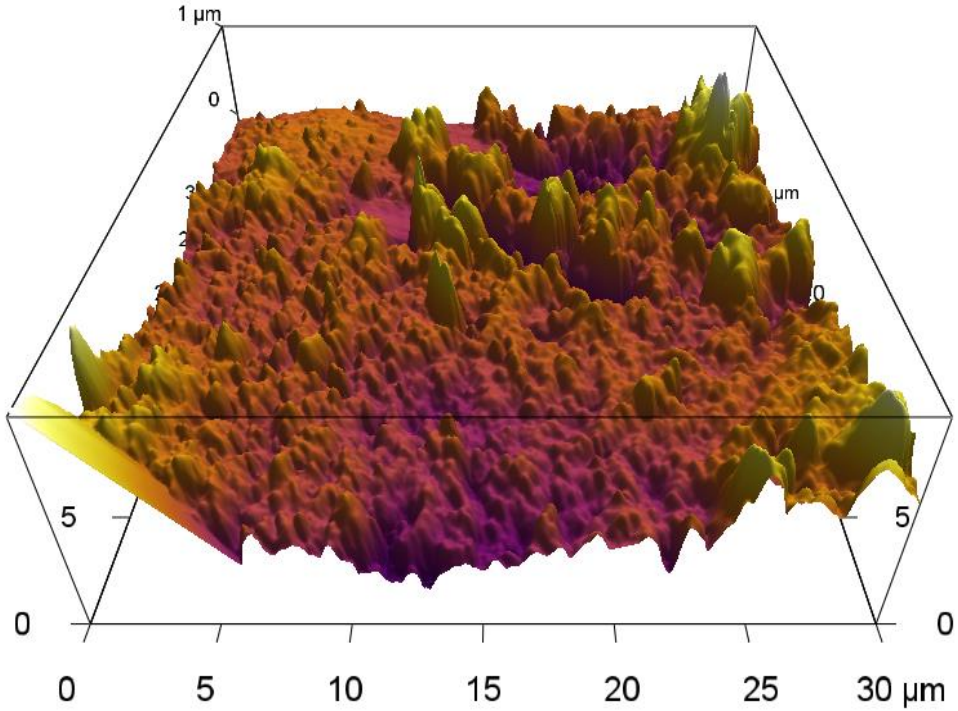
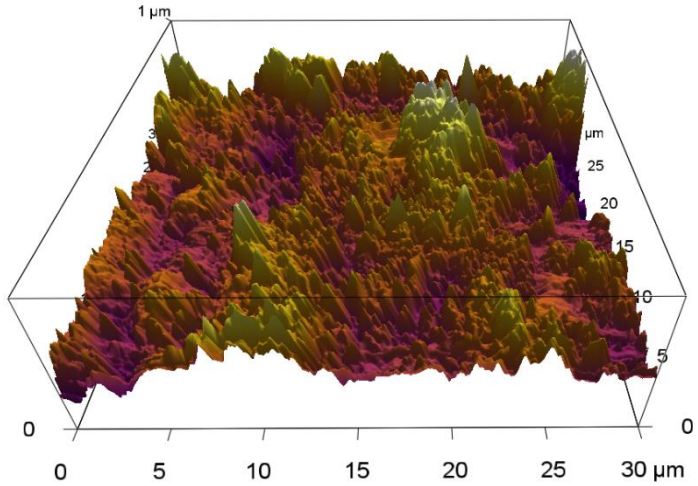
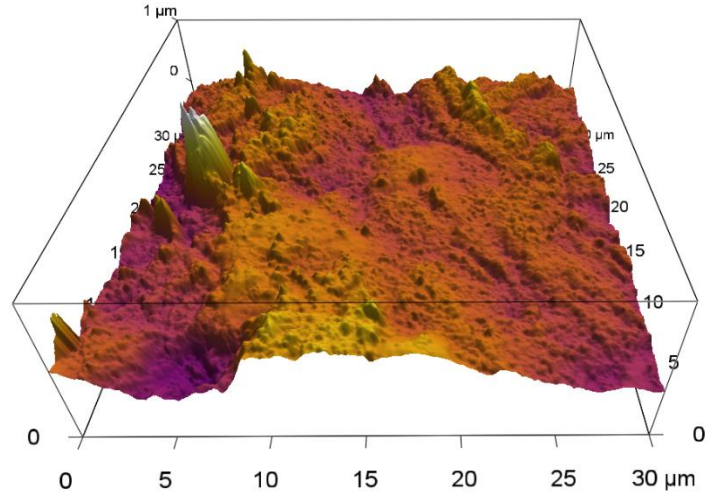
Effect of various surface treatments to enamel roughness

enamel slices without surface treatment

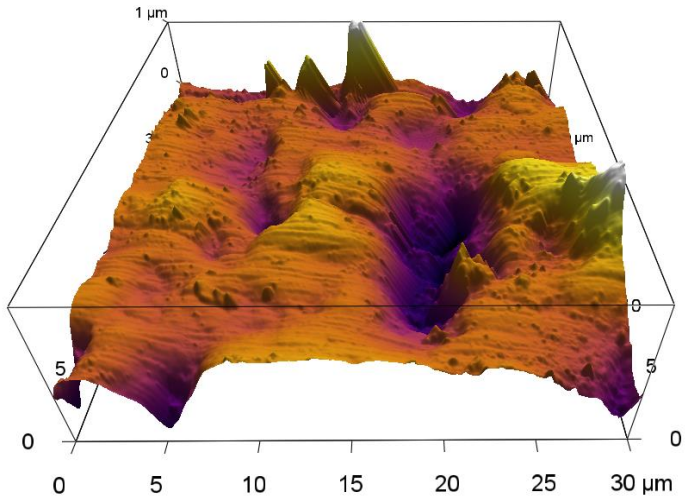




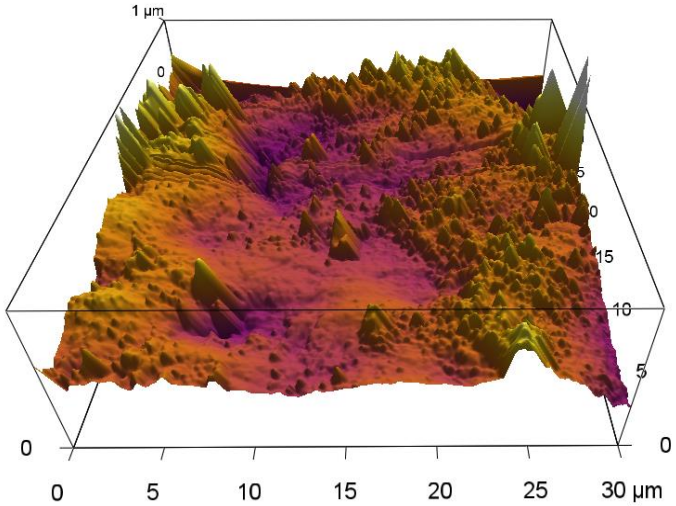
air-polished with a 54-µm particle size calcium carbonate prophylactic powder (5 s)



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