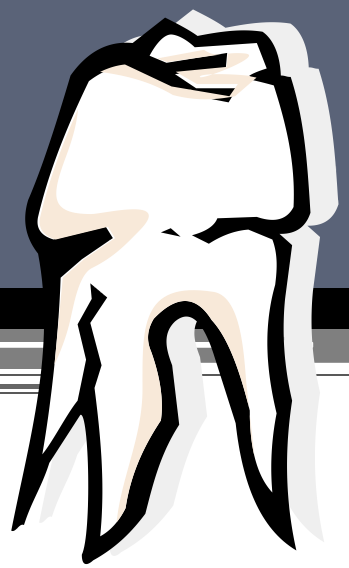
Tooth: chemical composition and structure



Lenka Fialová

Seminar – dentistry first year

Composition of mineralized tissues

	Inorganic part	Organic part	Water
Enamel	97 %	1,5 %	1,5 %
Dentine	70 %	20 %	10 %
Cement	60 %	25 %	15 %
Bone	65 %	25 %	10 %

Dentine

Composition of dentine

Dentine is a mineralized connective tissue and its composition and formation is similar as the bone.

- Cells
  - Odontoblasts
- Intercellular matrix
  - Organic part 20 %
  - Water 10 %
  - Inorganic part 70 %
    - hydroxyapatite crystals (uniform lamels)

Organic part of dentine

- Collagens — cca 90 %
- Noncollagen proteins — cca 10 %
- Proteoglycans

Organic part of dentine

Collagens

- Collagen type I 98 %
- Collagen type III, V 1 - 2 %

- Collagen fibers have net like structure in dentine.
- Collagen fibres form the boundary of three-dimensional structure, to which the inorganic material of dentine is deposited.

Organic part of dentine

Mineralization process needs the presence of collagen fibrils, and of other noncollagen proteins.

Noncollagen proteins

- Phosforylated matrix proteins
- Nonphosphorylated matrix proteins
- Enzymes
  - Metalloproteinases
  - Cathepsins
  - Alkaline phosphatase
- Blood serum proteins
- Growth factors

Organic part of dentine

Phosphorylated matrix proteins

- *These proteins have acidic nature, characterized by high content of glutamate and aspartate, and of phosphoserine (sythetized by posttranslational modification of the protein).*
- *The function of the above mentioned extracellular proteins is binding of calcium.*
- *These proteins are able to react with collagen fibrils bind to the cells.*

THE ROLE IN DENTINE MINERALIZATION

- *Theese proteins may act as iniciators and/or inhibitors of the mineralization process.*

Organic part of dentine

Phosphorylated matrix proteins

- Dentine sialophosphoprotein (DSPP)
- Dentine matrix protein-1 (DMP-1)
- Bone sialoprotein (BSP)
- Osteopontin (OPN)

The above mentioned proteins form a family of SIBLING proteins

(Small Integrin-Binding Ligand N-linked Glycoproteins), all having common structural characteristic.

Dentine sialophosphprotein (DSPP)

The highest content of dentine sialophosphoprotein is observed in dentine, however it is present also in cement and bone.

Dentine sialophosphoprotein is proteolytically degraded to following active proteins:

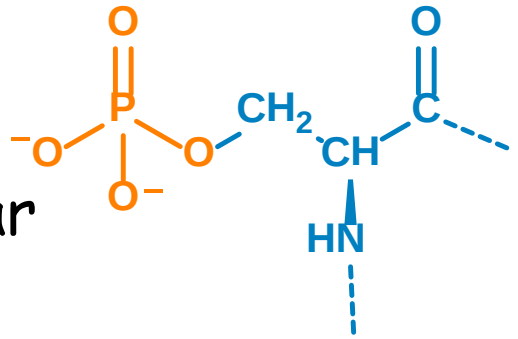
- dentine phosphoprotein (DPP)
- dentine sialoprotein (DSP)

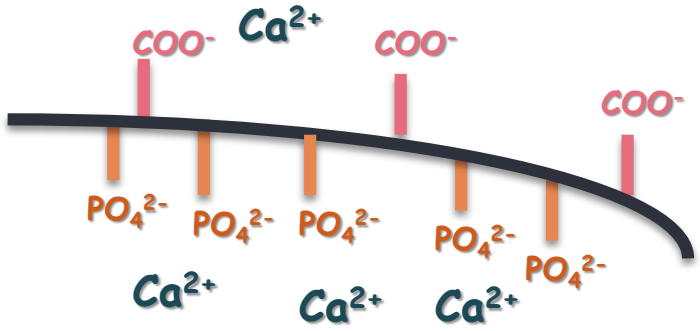
Dentine phosphoprotein (DPP)

Basic characteristic

- the most abundant noncollagen protein of the dentine extracellular matrix
- phosphoforyn – supposed to be a transporter of phosphate
- binding of Ca^{2+} ions
- binding to collagen

Phosphoserin residue





Dentine phosphoprotein (DPP)

Characteristic:

- High density of negative charges
  - high content of phosphoserine 45 – 50 %
  - high content of aspartate 35 – 38 %
  - arranged to repetitive sequences

$(Asp\text{–}phosphorylated\ Ser\text{-}phosphorylated\ Ser)_n$

$(Asp\text{–}phosphorylated\ Ser)_n$

↓

BINDING OF HIGH AMOUNT OF CALCIUM IONS

Formation of insoluble aggregates with Ca a Mg ions

Dentine phosphoprotein (DPP)

Function

- initiator and modulator of dentine mineralization
- in the region of the front of mineralization DPP binds close to the holes between individual monomers of collagen, where the first mineral deposites are formed – nucleation places
- affects the size and shape of apatite crystals → small strip-like crystalls

Dentine sialoprotein (DSP)

- Function not yet precisely defined

Dentine matrix protein-1 (DMP-1)

- multifunctional protein
  - takes part in biomineralization of dentine and bones
  - regulation cell differetiation (mesenchymal cell into odontoblasts) and cell attachment

Bone sialoprotein (BSP)

- takes part in mineralizaton process
- in dentine higher content than in predentine

Osteopontin

- Present in different tissues, its content in bones is higher than in dentine
- Capability to connect cells with the mineral component of the matrix (*pons* means bridge in Latin)

Organic part of dentine

Important nonphosphorylated matrix proteins

- Osteocalcin (rich in γ-carboxyglutamate)
- Osteonectin (acidic protein rich in cystein)

are members of a group of secreted calcium binding proteins.

Osteocalcin

Basic characteristic:

- low-molecular calcium binding protein
- most abundant noncollagen bone protein
- lower content in dentine

Osteocalcine

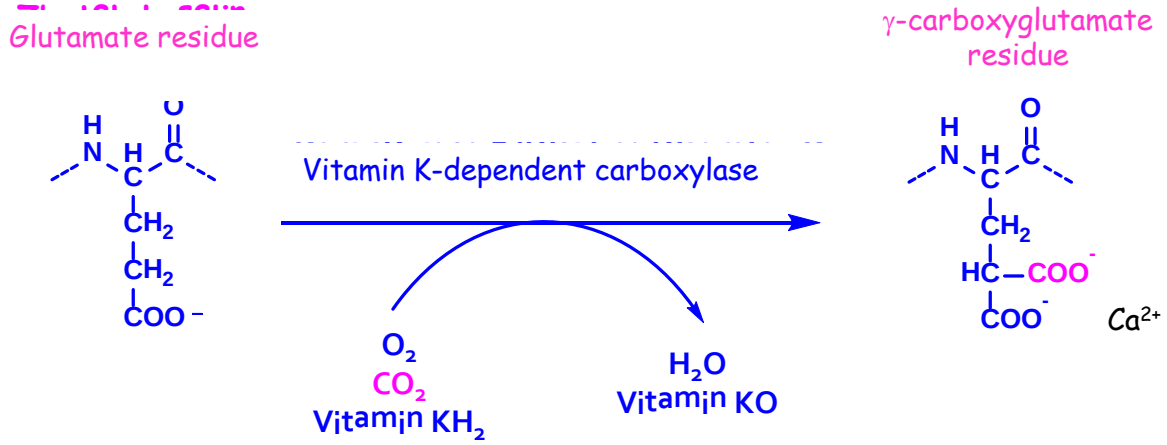
Characteristic:

- contains 3 residues of γ-carboxyglutamate
- synthesis of the protein depends on the presence of vitamin K

Function

- binding of hydroxyapatite by three residues of γ-carboxyglutamate
- inhibition or control of the hydroxyapatite crystalization

Posttranslational carboxylation of glutamate residues



- By posttranslational carboxylation of γ-carbons of glutamate originates the γ-carboxyglutamate (Gla). Gla shows high affinity to Ca^2 ions.
- The above mentioned posttranslational modification occurs not only during synthesis of osteocalcin, but also in the case of proteins taking part in hemocoagulation (Gla proteins).
- This enzymatically catalyzed reaction needs vitamin K.

Proteoglycans

- Chondroitinsulphates
- Keratansulphates

- are secreted to predentine and block the mineralization.
- they must be metabolized or removed prior to mineralization.

Dentinogenesis

- Predentine
  - Nonmineralized tissue
    - only organic part
- Dentine
  - Mineralized tissue
    - organic part
    - mineral part

Dentinogenesis

Predentine formation:

- Synthesis of organic matrix

Starts with formation of layer of nonmineralized matrix rich in collagen I by odontoblast (predentine).

Mineralization of organic matrix

- Precipitation of inorganic phase in region of front of mineralization

Predentine is transformed to dentine by deposition of mineral to organic matrix in form of hydroxyapatite crystals by controlled biomineralization process.

Enamel

Enamel

Covers the surface of dental crown.

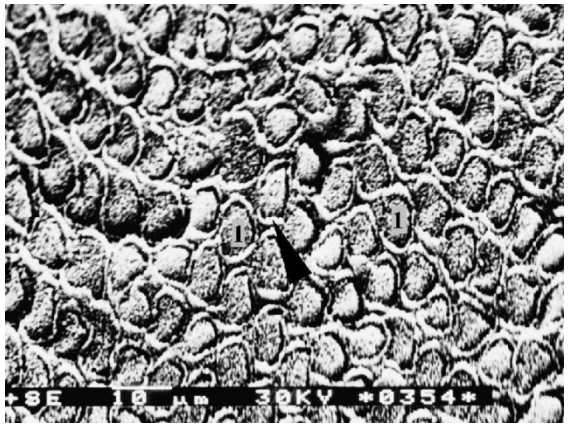
- The hardest mineralized tissue of human body resisting the forces of mastication.
- Semipermeable tissue
  - Penetration of different molecules – movement of ions into the enamel
    - E.g. fluorides presnt in toothpaste
- No resorption and remodelation as in the bone tissue.

Composition of enamel

- Inorganic part 97 %
- Organic matrix 1,5 %
  - Proteins, lipids
- Water 1,5 %
  - Bound water – in crystals as their hydratation cover
  - Free water – present in organic matrix

Inorganic part of enamel

- Enamel apatite
  - Hydroxyapatite
  - Fluoroapatite
  - Carbonateapatite
- Shape of apatite crystals
  - In cross-section approximatelly hexagonal
  - In side wiew rod-like shape
  - Crystals of enamel apatite are organized to the prisms, separated by interprismatic substance (organic matrix).



Organic part of the enamel

Proteins of enamel matrix

- *Mature ameloblasts secrete a mixture of proteins, glycoproteins and of proteolytic enzymes controlling the growth and formation of mineral phase.*
- *Proteins of enamel interact together and react also with with hydroxyapatite. In the course of enamel mineralisation almost all proteins are removed.*
- *Almost all proteins of the enamel matrix are in contrary to dentine noncollagen proteins nonphosphorylated.*
- *Collagen is not present in the enamel organic matrix.*

Organic part of enamel

Important proteins of the enamel matrix

- Amelogenins — cca 80 – 90 %
- Nonamelogenin proteins
  - Ameloblastin/amelin/sheathlin — cca 5 – 10 %
  - Enamelin — cca 1 – 5 %
  - Tuftelin
  - Enzymes – mainly proteinases

Amelogenins

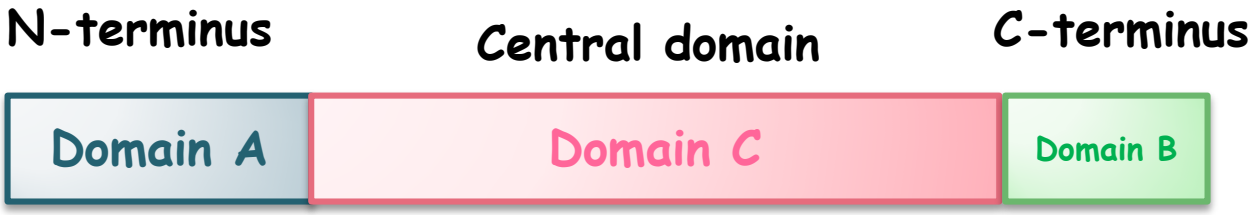
Basic charakteristic

- The most abundant proteins of the enamel organic matrix
- Main part of the newly secreted enamel
- Produced by ameloblasts in the secretion phase of the enamel formation
- Regulation of biomineralisation in the course of the secretion phase of enamel formation
- Hydrophobic protein with ability to aggreagate

Amelogenins

Charakteristic of the molecule

- N-terminal hydrophobic domain – DOMAIN A
- Central hydrophobic domain - DOMAIN C
- C-terminal, hydrophilic, acidic – DOMAIN B
  - Binding to hydroxyapatite
  - after secretion of the protein quickly removed proteolytically
  - Important in the early phase of enamel formation



Amelogenins

Grouping of amelogenine molecules

- Amelogenine molecules are able to polymerize. First the oligomers appear, which later form small, spheric particles (nanosphere), 20 nm in diameter.

- Contact of hydrophilic domain with hydroxapatite restricts the growth of crystals in circumference and affects the crystal lenght and thickness.

Enamel formation

Ameloblasts

- each ameloblast forms one prizm

Process of enamel formation is a result of interaction of different enamel proteins, which transitionally aggregate. The way of their arrangement controls the growth, structure and orientation of developing hydroxypatite crystals.

Enamel formation

- Secretion phase
  - Formation of organic matrix, which is mineralised in part.

- Maturation phase
  - After formation of enamel in full size and volume the mineralisation is completed. The proteins of the organic matrix (amelogenin and others) are degraded by proteolytic enzymes and also water is removed.

Cementum

Cementum

Cementum is a mineralised connective tissue covering dentine, in region of the root. The fibres of periodontal ligaments are anchored to cementum. The composition of cementum resembles the bone tissue.

Composition of the cementum

- Cells
  - Cementocytes
- Intercellular matter
  - Organic part 25 %
  - Inorganic part 60 %
    - Crystalls of hydroxyapatite and small amount of amorphous calciumphosphate

Organic part of cementum

- Collagens
  - Collagen type I 90 %
  - Collagen type III (covers collagen fibrils) 5 %
- Noncollagen proteins
  - Important for mineralisation process
    - Bone sialoprotein
    - Osteopontin
    - Osteonectin
    - Osteocalcin
    - Alkaline phosphatase
- Proteoglycans

The dental pulp

Copmposition of the dental pulp

- Main cells
  - Fibroblasts (s.c. pulpoblasts with two processes, synthetize the collagen fibrils and proteoglycans)
  - Makrophages (imunity - phagocytosis)

- Intercellular matter
  - Organic part 25 %
  - Water 75 %

Organic part

Substantially different from intercellular matter of dentine.

Dentine proteins taking part in the mineralisation are not present in pulp → the pulp is not able to mineralise

- Collagens
  - Collagen type I 56 %
  - Collagen type III 41 %
  - Collagen type V 2,5 %
  - Collagen VI 0,5 %

Organic part of the pulp

- Noncollagen proteins
  - Bone sialoprotein
  - Osteopontin
  - Fibronectin
  - Osteonectin
- Proteoglycans
  - Amount of PG in dental pulp is different than in dentine
    hyaluronic acid is present

Mineralised tissues

- Bone
  - Continuous remodelling of the bone
    - resorption and new formation of bone tissue
  - Reservoir of calcium, which can be released to extracellular liquid
  - Osteoblasts are in the course of bone formation embedded into the bone tissue

- Enamel and dentine
  - No remodellation. Enamel calcium is not used for regulation of the amount of calcium in extracellulár fluid
  - Odontoblasts are not embedded into the mineralised organic matrix