The dental pulp

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2016
The dental pulp (introduction)

- Structure of the pulp
- Extracellular matrix and cells in the pulp
- Blood and lymph supply of the pulp
- Innervation of the pulp
- Role of pathological changes in circulation in the development of tissue inflammation
- Regressive changes in the pulp
What is the dental pulp?

- Connective tissue infilling of the pulp chamber and upper root
- Remnant of the dental papilla
- It maintains health of dentine,
- repairs dentine,
- provides sensory pathways from dentine.
Radiograph of teeth – pulp chambers are visible well
Section of the tooth – pulp chamber is encapsulated

- Mantle dentin
- Pulp chamber with pulp
- Tercier dentin
- Primer dentin
- Szekunder dentin
- Predentin
Incisor longitudinal section

observe the central location of pulp cavity
Molar longitudinal section

The pulp fills in the pulp chamber and the root canal.
Tooth development

LAMINA

BUD STAGE

CAP STAGE

BELL STAGE

ERUPTION
Gene activation during tooth development

Epithelium

Mesenchyme

Oral ectoderm Otx2/Pitx2

Dental lamina Lef-1

Dlxl&2/-

Mesenchyme

Odontogenic mesenchyme
Lhx6,-7, Barx1
Msx1,-2
Dlxl,-2, Pax9

Condensed dental mesenchyme
Msx1, Pax9
Gli1,-2,-3
Lef1

BMP FGF

BMP FGF Shh Wnt

BMP FGF Activin

Enamel knot
p21, Msx-2

BMP FGF Shh Wnt

BMP FGF Wnt HGF

Dental papilla
Tooth development – details 1

I. The epithelial lining of the oral cavity before development commences

IV. Tooth bud

II. The primary epithelial thickening

V. Cap stage of development

III. Vestibular and dental laminae

VI. Vestibular sulcus (lip cleft)
Tooth development – details 2

I. Enamel organ

- Oral epithelium
- Outer enamel epithelium
- Stellate reticulum
- Intermediate cell layer
- Inner enamel epithelium

The Enamel organ develops from oral ectoderm.

II. Tooth germ

- Follicle
- Dental papilla
- Odontoblasts

The tooth germ consists of the enamel organ, the follicle and the dental papilla.

III. Formation of dentine and enamel

- Oral epithelium
- Ameloblasts
- Enamel
- Dentine
- Pulp
- Odontoblasts

IV. Root sheath of Hertwig

- Cell rests of Serres
- Follicle
- Bilaminar root sheath
- Pulp
Section of tooth – pulp is inside

I Matrix formation and mineralization
- Inner enamel epithelium
- Odontoblast with process
- Pulpal cells and fibers
- Unmineralized matrix

In the above sketch stippling indicates mineralization in both mantle and some circumpulpal dentine. Predentine is not mineralized.

II Mineralization
- Ameloblasts
- Calciospherites
- Odontoblasts
- Pulpal cells

Predentine (odontogenic zone)
- Mineralized dentine
- Enamel

III Intratubular (peritubular) and intertubular dentine (cross-section)
- Dentine tubule
- Intratubular dentine
- Coarse fibers of intertubular dentine
Fine structure of the pulp
Figure:
A) D: dentine; O: odontoblast; S.sz.: cell free zone; S.g: cell reach zone; C: central zone
B) O: odontoblast; IR: nerve fibres
Histochemical picture of pulp margin

- arterioles, venules, and nerve bundles
- capillaries and nerves
- odontoblasts
- predentine
dentine
Odontoblast layer between predentine and pulp

dentine

Mineralization front

Predentine

Odontoblasts

Mesenchyme
Constituents of the pulp

75 % water

and

25 % organic and water soluble inorganic material
Pulp Matrix

- Fibers are collagen type III, type I, and type V
  (Type III confers elasticity, Type I gives tensile strength, Type V also typical of mesenchymal tissue)

- Ground substance is made up of proteoglycans
  (which retain water to form gel and keep Ca^{2+} in solution)
Structure of collagen

Single polypeptide chain folded into a helix with 3.3 residues per turn

Three polypeptide chains folded together to form a triple-helical cable
Structure of proteoglycans

'Interstitial' proteoglycan

$M_r \approx 1000\,000$
Core $M_r \approx 400\,000$
GAG $M_r \approx 40\,000$
Leu-rich

'Two chain' small proteoglycan

$M_r \approx 120\,000$
Core $M_r \approx 38\,000$
GAG $M_r \approx 40\,000$

'One-chain' small proteoglycan

$M_r \approx 80\,000$
Core $M_r \approx 38\,000$
GAG $M_r \approx 40\,000$
Glu/Gln-rich
Cell Types in Pulp

1. Odontoblasts
2. Fibroblasts (maintain pulp matrix)
3. Undifferentiated Mesenchyme Cells
4. Macrophages
5. Accessory Cells (T-cells, dendritic cells, etc.)

Plus

• Blood vessels
• Nerve axons
Blood supply of the pulp

- It comes from branches of inferior and superior alveolar artery and vein.

- It is organized into larger central vessels (large venule and 1-2 arterioles) with a rich superficial plexus of capillaries around periphery in the crown.

- It is important for maintaining living cells (especially for odontoblasts) and for regulating fluid.

- Excess matrix fluid is removed by lymphatics.
Blood supply

\[ R = \frac{\Delta P}{Q} = \frac{128 \eta L}{\pi d^4 N} \]
Blood supply of the pulp

| VESSEL TYPE               | DIAMETER (μm) | Vm (mm/sec) | Q (10^-4 mm^3/sec) | Qa/Q  \\
<table>
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<tbody>
<tr>
<td>1st FEEDING ARTERIOLE</td>
<td>35 - 45</td>
<td>1.46 ± 0.11</td>
<td>16.68 ± 1.70</td>
<td>1.0</td>
</tr>
<tr>
<td>2nd FEEDING ARTERIOLE</td>
<td>24 - 34</td>
<td>1.08 ± 0.09</td>
<td>6.31 ± 0.71</td>
<td>2.8</td>
</tr>
<tr>
<td>TERMINAL ARTERIOLE (TA)</td>
<td>16 - 23</td>
<td>0.58 ± 0.06</td>
<td>1.71 ± 0.21</td>
<td>9.8</td>
</tr>
<tr>
<td>PRE-CAPILLARY (PC)</td>
<td>12 - 15</td>
<td>0.48 ± 0.13</td>
<td>0.82 ± 0.27</td>
<td>20.3</td>
</tr>
<tr>
<td>CAPILLARY (C)</td>
<td>&gt; 8</td>
<td>0.27 ± 0.03</td>
<td>0.16 ± 0.01</td>
<td>104.2</td>
</tr>
<tr>
<td>POST-CAP VENULE (PCV)</td>
<td>12 - 23</td>
<td>0.20 ± 0.02</td>
<td>0.57 ± 0.06</td>
<td>20.2</td>
</tr>
<tr>
<td>COLLECTING VENULE (CV)</td>
<td>24 - 50</td>
<td>0.37 ± 0.03</td>
<td>3.58 ± 0.54</td>
<td>4.7</td>
</tr>
<tr>
<td>VENULE (V)</td>
<td>&gt; 50</td>
<td>0.57 ± 0.05</td>
<td>16.83 ± 1.75</td>
<td>1.0</td>
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Vm = \( \frac{VcL}{1.6} \) (Mean Velocity)

Q = Vm • \( \frac{πD^2}{4} \) (Volumetric Flow Rate)
Blood supply of the pulp

Capillary loops
Pre-capillary
Terminal arteriole
Arteriole
AVA
Collecting venule
Lymphatic vessel
Venule
Arterioles and venules
Root canal with pulp vessels
Capillary network in the pulp
Nerve supply of the pulp

- The pulp is supplied by sensory fibers of the trigeminal nerve (V) and by sympathetic fibers of the gl cervicalis superior.
- It contains both myelinated and unmyelinated axons.
- Contains both sensory (CGRP, SP, NKA release) and sympathetic fibers (NA, NPY) (the latter regulates blood flow).
- A single tooth may contain 2000 A-delta myelinated axons (to conduct sharp, piercing pain) and 500 C type unmyelinated ones (to conduct dull ache in response to thermal, mechanical, and chemical stimuli).
- Fibers are concentrated in plexus beneath the odontoblast layer (subodontic or Rashkov’s plexus).
- Nerve fibers may extend into dentine tubules, most concentrated at pulp horns or in areas undergoing repair.
Network of nerve fibres in the pulp
Hemodynamics in pulp vessels – Starling forces

Capillary hydrostatic pressure

Interstitial fluid colloid-osmotic pressure

Interstitial fluid hydrostatic pressure

Plasma colloid-osmotic pressure

Net filtration

Lymphatic

$P_c$

$\Pi_l$

$P_i$

$\Pi_p$
Blood pressure fall along the extrapulpal (broken line) and intrapulpal (solid line) blood vessels. (Modified from Tønder, 1980.)
Effect of grinding on pulpal blood flow
Significance of arterio-venous anastomoses (AVA)
Pulpal blood flow and sensory nerve activity
Hemodynamic regulation of blood flow - role of alpha₁ adrenoceptors

Haemodynamic regulation

![Graphs showing the effect of symp, saline, and NE on pulpal blood flow with and without Phenoxybenzamine (α-blocker).](image-url)
Figure 7. Convergence of afferent inputs onto nociceptive neurones in trigeminal subnucleus caudalis (medullary dorsal horn) or its analogous structure in the spinal cord. Some afferents are excited only by superficial afferent inputs from skin (or mucosa), others by superficial and one or more of the deep afferent inputs (e.g. from joint, muscle, tooth pulp). (From Hu, J.W. Cephalic myofascial pain pathways. In: Olesen, J. and Schoenen, J. (Eds.) Tension-type Headache: Classification, Mechanisms, and Treatment. Raven Press: New York, p. 69–77, 1993.)
Current concepts on the generation of dentinal pain

- Osmotic, thermal, and mechanical stimuli
- Fast conduction (low threshold)
- Mechanoreceptor?
- Aβ fibers
- Hydrodynamic effect
- Fluid flow
- Modulating factors
- Odontoblastic process
- Aδ fibers (first pain)
- Patency of tubules
  - Smear layer
  - Sclerosis
- Noxious chemical or thermal stimuli
- Diffusion
- Modulating factors
- Tubule content
- Depth of dentin
- C fibers
  - Long-lasting pain
  - Odontoblast
  - Inflammation
  - Bradykinin
  - PGE₂
  - SP
  - CGRP
  - Leukotrienes
  - Acids
  - C Fiber subject to peripheral and central sensitization (plasticity)
Sensation from tooth to brain

- Cortex pain
- Brain stem
- Trigeminal ganglion
- Sensory nerves
- Vessel
- CGRP SP
- Hydrodynamic stimuli

Diagram showing the pathways from tooth to brain, including sensory nerves, trigeminal ganglion, and involvement of CGRP and SP in vessel interactions.
Sensory Inputs

- Facial skin
- Oral mucosa
- Tooth
- Cranial vessels
- Muscle
- TMJ

CEREBRAL CORTEX

THALAMUS

MAIN SENSORY

ORALIS

INTERPOLARIS

RF

CAUDALIS

SPINAL CORD

TRIGEMINAL GANGLION

BRAIN STEM
General position of afferent nerve endings in the odontoblastic layer, the predentin, and the dentin

**Od**: odontoblastic layer, **SP**: substance P, **CGRP**: calcitonin gene-released peptide, **BV**: blood vessels, **PAN**: primary afferent nociceptor, **SPGN**: sympathetic postganglionic nerves
Release of neuropeptides from sensory nerve fibers

Nociceptive stimulation to center C-type polimodal afferent

Mast cell

histamine

capillary network

arteriole

C-type polimodal afferent
to center
	nociceptive stimulation

Mast cell

histamine

capillary network

arteriole

SP, CGRP, NKA
Potential mechanisms that lead to the sensitization of primary afferent nociceptors (PAN)
Sensitization of primary afferent nociceptors (PAN) by arachidonic acid (AA) cascade and by the phospholipase A-activating protein (PALP)
Responses to Tissue Injury

Nociceptor discharge
Vasodilation
Plasma extravasation
Mast cell degranulation
Arachidonic acid cascade
Lymphocyte + neutrophil invasion
Nociceptor sensitization
Epithelial proliferation
Collagen synthesis
Regulation of gene expression
Phenotype changes

Important definitions:

Hyperesthesia

Hyperalgesia

Allodynia

Anesthesia

Analgesia

Figure 14. Schematic relationship between stimulus intensity (e.g., temperature or pressure) and the sensation evoked. ABC represents the normal relationship. A certain stimulus intensity is required in order to be detected by the subject (A: sensory threshold). As the stimulus intensity increases, there is an increased sensation (e.g. of warmth or pressure but not pain) until the pain threshold is reached (B). If the stimulus intensity continues to increase, there is an increased sensation of pain until the tolerance threshold is reached (C). In conditions with tissue injury pain and nervous system injury pain there is a shift of the stimulus-response curve to the left (arrow). DEG suggests decreased thresholds but also increased sensations at a given stimulus intensity, compared to ABC. DE represents hyperaesthesia, EF allodynia and FG hyperalgesia.
Analgetic system transmitting endogenous pain suppression

Periaq. nuclei

Medulla

Spinal chord

opioid inhibitory neuron

GABAergic inh. neuron

monoaminergic inh. neuron

Morphine

Inhibitory mechanism

Pre- & postsynaptic inhibition

Opioid inh. interneuron (lower)
morphine
Pain development: gate control theory

A: stimulator effect, SG: spinal ganglion, B: interneuron, T: transmitting neurons
Pain

“An unpleasant sensory and emotional experience arising from actual or potential tissue damage or described in terms of such damage.”

International Association
for the Study of Pain
Thermoreceptors in dental pulp are similar to skin

Responses of thermoreceptors in relation to skin temperature
The rate of pain depends on the level of heat exposure.
Development of increased intrapulpal pressure
- misbalance in inflamed tissue
**Vicious circle of pulp inflammation**

- Increased capillary pressure
- Increased venous blood pressure
- Compression of venules
- Increased capillary filtration
- Increased vessel permeability
- Increased fluid volume
- Adsorption in noninflamed area
- Vasodilation
- Tissue pressure

**Vicious circle**

- Blood vessel
- Lymph vessel
Regressive changes in pulp

• It progresses gradually and continuously with age
  - diameter of pulp chamber decreases

• Sclerotic alterations (blood vessel wall calcification)

• Denticuli (pulp stones)
  - denticuli (produced by odontoblasts)
  - false denticuli (spontaneous calcification)
The dental pulp (summary)

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