DENTAL PULP
Dental pulp is connective tissue uniquely situated within the rigid encasement of mineralized dentin; although dental pulp shares many properties with other connective tissues of the body; the peculiar location of dental pulp imposes several special characteristics on it.
HISTOGENESIS OF THE DENTAL PULP
The pulp is derived from the mesenchyme and ectomesenchyme;
The pulp is formed from the second element of the tooth germ - dental papilla;
The most important developmental events are those guiding epithelial-ectomesenchymal interactions, which involve a molecular crosstalk between the ectoderm and ectomesenchyme, two tissues that have a different origine.
As the dental lamina continues to grow and thicken to form a bud, cells of the ectomesenchyme proliferate and condense to form the dental papilla; At this stage, the inductive or tooth-forming potential is transferred from the dental epithelium to the dental papilla.
At this stage, the tooth bud assumes the shape of a cap that surrounded the dental papilla;

Another layer of mesenchymal cells, called the dental follicle, that separates the tooth organ papilla from the other connective tissues of the jaws;

The enamel knot expresses a unique set of signaling molecules that influence both the shape of the crown and the development of the dental papilla.
The reciprocal exchange of molecular information between the dental organ and dental papilla influences the important events that lead to cell differentiation at the late bell stage.
The cardiovascular system originated from cells termed angioblasts, which arise from angiogenic clusters from the visceral mesoderm;

As these cells separate into clusters, the outer cells organize into a series of elongating tubes;

The inner cells become blood cells.
Vascularisation of the developing pulp starts during the bell stages, with small branches from the principal vascular trunks of the jaw entering the base of the papilla.

The principal vessels enlarge and run through the pulp towards the cuspal regions.

Here they give of numerous small branches, which form a bed of venules, arterioles and capillaries in the subodontoblastic and odontoblastic layers.
The most peripheral cells of the dental papilla enlarge and become organized along the basement membrane at the tooth`s epithelial-mesenchymal interface;

These newly differentiated cells are called odontoblasts;

They are the cells that are responsible for the synthesis and secretion of dentin matrix;

At this time, dental papilla is termed the dental pulp.
FORMING TOOTH PULP

- Ameloblasts
- Pre-dentin
- Odontoblasts
- Pre-enamel
- Forming tooth pulp
There is a great deal of evidence that dentin and the pulp are functionally coupled and hence integrated as a tissue;

Developmentally, pulpal cells produce dentin, nerves, and blood vessels;

Although dentin and pulp have different structures and compositions, once formed they react to stimuli as a functional unit.
Beginning of the pulpal histogenesis is bud stage of tooth;
The end of this process is the completion of the tooth root;
Throughout this period the dental pulp is in its embryonic stage.

As more and more dentin is deposited, the pulp chamber narrows and finally forms a canal containing blood vessels and nerves of the tooth.
Bone
Enamel organ
Acrodin cap (decalcified)
Dentine
Odontoblasts
Pulp cavity

1 mm

Developing tooth deep in socket; no ankylosus

Developing tooth deep in socket; no ankylosus
The end of this process is the completion of the tooth root.
Incomplete root development.
PERIODS IN THE PULP LIFE

- Embryonic - from the beginning of the pulp build up to the complete root formation and closure of the apex.
- Functional - after closure of the apex.
- Senile - for the primary teeth such period is missing, and for the permanent teeth - with the advancing age.
Connective tissue is the supporting tissues widely distributed throughout the body;
The major constituent of connective tissue is:

- **Extracellular matrix**, which is mainly composed of fibrillar protein and ground substance;
- **Cells** - fibroblasts are the principal cells in connective tissue;
- **Other cellular elements** include blood-derived defensive cells, such as macrophages, whose primary function is to cope with infection.
In the central core of the pulp, the basic components are arranged in a manner similar to that found in other loose connective tissues.
There are two types of fibrillar proteins:
- Collagen;
- Elastin;
Collagen is the more abundant type and its main component of collagen fibers, which confer strength of the tissue;
Elastin provide elasticity to the tissue;

In the pulp, elastic fibers are distributed only in the walls of the larger blood vessels.

Compare collagen shown in blue with red side thingies, with elastin shown in yellow.

The curly protein shape of elastin proteins and weird cross links going every which way, allow elastin to spring back after stretching, whereas collagen doesn't give so much.
The blue diagonal line is a single tropocollagen (pre-collagen unit). They combine into the triple helix (three stranded rope) of a collagen molecule (lower middle). The yellow snaky one is elastin - like a rubber band. The thin cobweb-like fibers are reticulin - immature collagen found mostly in embryos.
It is responsible primarily for the viscoelasticity and filtration function of connective tissue;

It is mainly composed of:

- Proteoglycans, which consist of protein core and polysaccharide side chains called glycosaminoglycans;
- Adhesive glycoproteins such as fibronectin, which primarily function to mediate cell-matrix interaction.

The proteoglycans are composed of glycosaminoglycan (GAG) chains.
Illustration of a *proteoglycan* molecule inside extracellular matrix.

Chondroitin sulfate *proteoglycans* (CSPGs)
TYPES OF CONNECTIVE TISSUE

- Loose connective tissue;
- Dense connective tissue;
- Dental pulp is classified as a loose connective tissue.
Loose connective tissue, which is rich in ground substance and contains relatively fewer fibers.
Dense connective tissue, which is characterized by a clear predominance of collagen fibers and fewer cells;
The major function of connective tissue is:

- To provide matrix that binds cells and organs;
- To give support to the body;
- It is also responsible for various activities that initiate and orchestrate reactions to pathogenic invasion, and thus it serves as an essential site of host defense;
- It also has a remarkable capacity to repair damaged tissue in the form of scarring.
The first function - to provide matrix that binds cells and organs

Normal tissue

- Hyaluronan
- Collagen
- Lymph vessel
- Fibroblast
- Blood vessel
- Proteoglycan

Hyaluronan; Collagen; Lymph vessel; Fibroblast; Blood vessel; Proteoglycan.
SECOND FUNCTION - TO GIVES SUPPORT TO THE BODY
The pulp consists of coronal and root pulp;
Coronal pulp is larger and contains many more elements than root pulp;
Root pulp acts as a conducting tube to carry blood to and from the coronal area to the apical canal;
Both pulp areas contain the same elements, although the cells, fibers, blood vessels, and nerves are more numerous in coronal pulp.
Peripheral area of pulp is highly organized;
Central pulp - parietal layer or pulp core - pulpal to cell-rich zone.
(1) dentin-forming odontoblasts (A).
(2) reticular (Korff's) fibers (B) pass from the central pulp region, across the cell-free zone and between the odontoblasts, their distal ends incorporated into the matrix of the dentin layer;
Numerous capillaries (C) and nerves (D) are also found in this zone;
Just under the cell-free zone is the cell-rich zone (3) containing numerous fibroblasts (E) - the predominant cell type of pulp;
Fibroblasts of the pulp have demonstrated the ability to form as well as degrade collagen;
Perivascular cells (undifferentiated mesenchymal cells) are present in the pulp and can give rise to odontoblasts, fibroblasts or macrophages.
Since odontoblasts themselves are incapable of cell division, any dental procedure that relies on the formation of new dentin (F) after destruction of odontoblasts, depends on the differentiation of new odontoblasts from these multipotential cells of the pulp;
Lymphocytes, plasma cells and eosinophils are other cell types also common in dental pulp.
Medial to the cell-rich zone is the deep pulp cavity (4) that contains subodontoblastic plexus (of Raschkow; parietal layer) of nerves (G).
PERIPHERAL AREA OF PULP

- Odontogenic zone includes the odontoblasts;
- The cell-free zone is known as the zone of Weill or Weil’s basal layer;
- Cell-rich zone - adjacent to zone of Weil zone of high cell density;

FIGURE 1- General view of the dentin-pulp complex. Below the tubular dentin (D) there is the predentin (Pd), which is underlined by the odontoblast layer (Od). Observe the cell-free zone of Weil – horizontal arrow) and the cell-rich zone (vertical arrows). HE, x64
Odontogenic zone includes the odontoblasts;

The cell-free zone is known as the zone of Weill or Weil's basal layer;

Cell-rich zone - adjacent to zone of Weil zone of high cell density;

Central pulp - parietal layer or pulp core - pulpal to cell-rich zone:
- The peripheral odontogenic zone;
- Immediately subjacent to the odontoblast layer is the cell-free zone (of Weil); numerous bundles of reticular (Korff's) fibers; Numerous capillaries and nerves;
- Just under is the cell-rich zone;
- Perivascular cells (undifferentiated mesenchymal cells);
- Cell-rich zone is the deep pulp cavity that contains subodontoblastic plexus (of Raschkow; parietal layer) of nerves.
Which is characterized by the major vessels and nerves of the pulp, collagen-fiber bundles, cells and extracellular matrix and ground substance.
The central region of coronal pulp exhibits large blood vessels (A) and an extensive arrangement of nerves (B) that arise from large nerve trunks (C) and ascend to the more peripherally-located plexuses;

These structures are surrounded by a dense meshwork of fibroblasts and collagen fibers embedded in an intercellular matrix;

There are also numerous undifferentiated cells which may be called into action when a new odontoblast or fibroblast is needed;

Macrophages are commonly found within the pulp aiding in its maintenance;

Inflammatory cells may be present in varying numbers dependent upon the health of the tooth.
Collagen-fiber bundles are much more numerous in the root pulp than the coronal pulp.
The outermost part of the pulp is a layer of odontoblasts, the specialized cells that elaborate dentin;

They form a single layer with cell body in the pulp and long cytoplasmic odontoblastic processes extending into the dentinal tubules;

The shape of the cell body is not uniform, rather these cells are tall and columnar in the coronal pulp, short and columnar in the midportion of the tooth, and cuboidal to flat in the root portion.
A network of capillaries exist within the odontoblast layer;

There exist nerve fibers (terminal axons that exist from the plexus of Rashkow) that pass between the odontoblasts as free nerve ending.

Illustrates the free nerve endings (F) arising from the subodontoblastic plexus (E) and passing up between odontoblasts (A) to enter the dentinal tubule where they terminate (G) on the odontoblast process (D).
PERIPHERAL PULP AND ITS PRINCIPAL ELEMENTS

- Nerve ending between the odontoblasts;
- Capillary loop between odontoblasts.
- Showing dentin (D), predentin (P), odontoblast layer (O), cell-free zone (CF), cell-rich zone (CR), and central pulp (CP);
- **Cell-free zone contains large numbers of small nerves and capillaries.**
- Underlying **cell-rich zone** does not have high concentration of cells but contains more cells than does central pulp.
- **Pulpal surface of odontoblast contains layer of terminal raveling of nerves.**
Major constituents of this zone include:
- The rich network of mostly unmyelinated nerve fibers;
- Blood capillaries;
- Processes of odontoblasts and fibroblasts;

This zone is often inconspicuous when the odontoblasts are actively forming dentin.
Cell-free Zone

Dentin Matrix

Odontoblasts

Cell-free Zone

Cell-rich Zone

Dentin
More deeply situated pulpward is the cell-rich zone, which has a relatively high density of cells;

The constituents of this zone are basically the same as those in the pulp proper:
- Fibroblasts;
- Undifferentiated mesenchymal cells;
- Defense cells (macrophages and lymphocytes);
- Blood capillaries;
- Nerves;

This zone is discernible due to its higher density of fibroblasts than the pulp proper and is much more prominent in the coronal pulp than in the root pulp;
Dental pulp is richly innervated; it follows the same course as the blood vessels. Each nerve fiber may provide at least eight terminal branches, which again gives to an extensive plexus of nerves in the cell free zone. Thus plexus of nervous is called the Sub-Odontoblastic plexus or plexus of Raschkow. The nerve entering the pulp consists principally of sensory afferents of the trigeminal nerve and sympathetic branches form the superior cervical ganglions. There are two types of nerve fibers.

1) Delta fibers, which are unmyelinated fast conducting fibers of diameter 1-6µm and associated with conduction of sharp, localized pain when the dentin is first exposed.
2) Myelinated fibers slower conducting and smaller in diameter (2µm) and are associated with conduction of dull diffuse pain.
3) Rouget`s cell or pericytes are seen on the periphery of the capillaries and they supposedly serve as contractile cells capable of reducing the size of vessel lumen.
It has been suggested that this zone is a source of cells that differentiate into secondary (replacement) odontoblasts.
From the cell-rich zone inward is the central connective tissue mass known as pulp proper or pulp core;

This zone contain:
- fibroblasts, the most abundant cell type;
- Larger blood vessels;
- Nerves;
- Undifferentiated mesenchymal cells and defense cells (macrophages are frequently located in the perivascular area);
- Collagen-fiber bundles.
- A. Arterioles;
- B. Venules;
- C. Nerve bundle.

C = Capillary
FB = Fibroblast
FC = Fibrocyte
E = Elastic Fibers
L = Lymphocyte
A. Collagen fibers;
B. Arterioles;
C. Fibroblasts.
Of the collagen molecules occurring in the pulp, types I and III represent the bulk of tissue collagen;

Type I is the predominant type may contribute to the establishment of the architecture of the pulp - it is found in thick, striated fibrils;

Type III collagen in the pulp is also high - it appears as fine-branched filaments similar to that of reticular fibers.
COLLAGEN FIBERS
COLLAGEN FIBERS, NERVES AND BLOOD VESSEL
Mesenchymal cells (A), some fibroblasts (B) and macrophages. The first two cell types exhibit a stellate morphology and become reduced in number as the dental papilla transforms into pulp. Capillaries and nerves have invaded the dental papilla at this point of development. Nerves are not evident but a capillary (C) lies in the far right of the field. Only collagen and reticular fibers are present in the pulp.
Fibroblasts are the most numerous connective tissue cells in the pulp;
They have capacity to synthesize and maintain connective tissue matrix;
They are found in high densities in the cell-rich zone;
Syntesis of collagens type I and type III is a main function of fibroblasts in the pulp;
They are also responsible for the syntesis and secretion of a wide range of noncollagenous extracellular matrix components such as proteoglycans and fibronectin.
The morphology of pulp fibroblasts varies according to their functional state;

- Intensely syntetic cells have several irregularly branched cytoplasmic processes with a nucleus located at one end of the cell;

- They are rich in rough endoplasmic reticulum, and the Golgi complex is well developed.
FIBROBLAST

A

B

C

D

E

F
The fibroblasts in older pulp, are smaller than the active cells and tend to be spindle-shaped with fewer processes;
The amount of rough endoplasmic reticulum in these cells is also smaller;
When the quiescent cells are adequately stimulated, there synthetic activity may be reactivated.
Fibroblasts are implicated in the degradation of extracellular matrix components and thus are essential in the remodeling of connective tissues;

Fibroblasts are able to phagocytose collagen fibrils and digest them intracellularly by lysosomal enzymes;

Moreover, these cells are a source of a group of zinc enzymes called matrix metalloproteinases, that degrade matrix macromolecules such as collagens and proteoglycans.
UNDIFFERENTIATED MESENCHYMAL CELLS

- They are distributed throughout the cell-rich zone and the pulp core, frequently occupying the perivascular area;
- These cells appear as stellate-shaped cells with a relatively high nucleus-to-cytoplasmic ratio;
- However, they are usually difficult to distinguish from fibroblasts;
- After receiving appropriate stimuli, they may undergo terminal differentiation and give rise either to fibroblasts or to odontoblasts;
- In older pulps, their number may diminish, which may also reduce the regenerative potential of the pulp.
UNDIFFERENTIATED MESENCHYMAL CELLS

- Ameloblasts
- Pre-dentin
- Odontoblasts
- Pre-enamel
- Forming tooth pulp
The ability of connective tissue to generate and support local inflammatory and immune reactions makes it an active participant in host defense;

A considerable part of this capacity depends on immunocompetent cells resident in the tissue;

These cells are recruited from the bloodstream, where they reside as somewhat transient inhabitants
The specificity of immune responses is due to lymphocytes, for they are the only cells in the body capable of specifically recognizing different antigens;

T-lymphocytes are recognized as normal residents of pulp;

They are scattered predominantly along the blood vessels in the pulp proper;

It seems difficult to identify a significant role for B lymphocytes in the normal pulp.
LYMPHOCYTES

Specific immune cells;

They have large round nucleus;

They occur in chronic pulp inflammation
Macrophages are constituents of the mononuclear phagocyte system, which consists of heterogeneous populations of bone marrow-derived cells whose primary function is phagocytose and digest foreign particles as well as self-tissues and cells that are injured or dead;

That are activated by:

- Various bioactive substances such as bactericidal enzymes;
- Reactive oxygen species;
- Cytokines;
- Growth factors;

Macrophages show diversity in terms of morphology, phenotype and function;

Morphology of macrophages varies to state of activation and differentiation;
MACROPHAGES

- They are generally characterized by an irregular surface with protrusion and indentations;
- A well-developed Golgi complex;
- Many lysosomes;
- A prominent rough endoplasmic reticulum.
MACROPHAGES IN THE PULP

- They are described as histiocytes located in the vicinity of blood vessels;
- They are particularly rich in the perivascular area of the inner pulp;
MACROPHAGE IN THE PULP
DENDRITIC CELLS

- They are hematopoietically derived leukocytes sparsely distributed in almost all tissues;
- They are characterized by peculiar dendritic morphology, high motility, limited phagocytic activity and potent capacity for antigen presentation to T lymphocytes;
- They are rich in the periphery of the pulp (in and just subjacent to the odontoblasts);
- Also rich in the perivascular area.
They are observed in acute inflammation;
Larger than lymphocytes; a typical characteristic is chromatin aggregation in the nucleus as a "clock."
They occur in small groups in relation to blood vessels;

Mast cells are seldom found in the normal pulp tissue;

They are routinely found in chronically inflamed pulp.
The dental pulp is a microcirculatory system because it lacks true arteries and veins;
The largest vessels are arterioles and venules;
Its primary function is to regulate the local interstitial environment via transport of nutrients, hormones, and gases and the removal of metabolic waste products;
It also responds to inflammatory stimuli with a great change in circulatory properties.
The vascularity of the odontoblastic layer increases as dentin is progressively laid down, since the odontoblasts retreating onwards through the vascular bed.

Some capillaries are found immediately next to the pre-dentinal surface, which some time trapped in the dentine to form capillary loop.

Pulpal blood flow is more rapid than in must areas of the body. Pulpal pressure is among the highest of body tissues. Flow of blood in arteries - 0.3 to 1mm per second; Veins - 0.15mm/sec and Capillaries - 0.08mm/sec
- The walls of pulpal vessels are very thin as the pulp is protected by a hard unyielding sheath of dentin;
- One or more small arterioles enter the pulp via the apical foramen and ascend through the radicular pulp of the root canal;
- Once they reach the pulp chamber in the crown they branch out peripherally to form a dense capillary network immediately under - and sometimes extending up into - the odontoblast layer;
- The capillaries exhibit numerous pores, reflecting the metabolic activity of the odontoblast layer;
- Small venules drain the capillary bed and eventually leave as veins via the apical foramen.
Microcirculatory organization of the subodontoblastic region is divided into three major layers:

- Arterole;
- Terminal arteriole;
- Pre-capillary;
- Capillary loops;
- Collecting venule;
- Venule.
The arterioles are resistance vessels, measuring approximately 50µm in diameter;
They have several layers of smooth muscle, which regulate vascular tone;
The transitional structure between arterioles and capillaries is called terminal arteriole;
They are surrounded by a few smooth muscle cells with a spiral fashion surrounding the endothelial cells;
The arterioles then divide into terminal arterioles and then precapillaries;
Metarterioles give off capillaries, which are about 8µm in diameter.
The arterioles, the capillaries, and the venules form functional units that respond to signals elaborated from the nearby tissue;

This is an important concept, because virtually every cell in the body is within 50 to 100µm of capillaries;

Thus, there is a functional coupling between cellular activity and nearby capillary blood flow;

B, Higher magnification. C. arterioles - artery branching off to form a capillary network of the pulp surface of the root;

Venules (V) are about 50 micrometers in diameter. Arterioles are about 10 micrometers in diameter.
The presence of clumps of smooth muscle that serve as precapillary sphincters;

These sphincters are under neuronal and local cellular control and act to regulate local blood flow through a capillary bed;

These functional units permit localized changes in blood flow and capillary filtration, so that adjacent regions of the pulp have substantially different circulatory condition;

Thus, pulpal inflammation can elicit a localized circulatory response restricted to the area of inflammation and does not necessarily produce pulpwide circulatory changes.
Capillaries are as the workhorse of the circulatory system, because they function as the exchange vessels regulating the transport or diffusion of substances between blood and local interstitial tissue elements;

At any given moment, only about 5% of the blood supply circulate in capillaries, but this is the major site of nutrient and gas exchange with local tissues;

Capillaries consist of single layer of endothelium;

They form extensive loops in the subodontoblastic region;

The wall of a capillary is about 0.5 µm thick and serves as a semipermeable membrane.
There are several major classes of capillaries that differ dramatically in their properties as semipermeable membranes:

1. Fenestrated capillary - they characterized by endothelium with openings (fenestrations) in the capillary walls. They can open or occluded by a thin diaphragm;

2. Continuous (or nonfenestrated) capillary - the intercellular space contains gap junctions, which are localized opening with of 5 to 10 nm;

3. Discontinuous capillary with discontinuous endothelium;
Pre-capillary;
- Capillary;
- Postcapillary;
- Blood flow is determined by hydrostatic and oncotic pressure
Anastomoses are points of direct communication between the arterial and venous sides of the circulation;

Blood flow is more rapid in the pulp than in most areas of the body and the blood pressure is quite high.
Arteriovenous anastomoses of arteriolar size are frequent in the pulp.
Circulation of blood and blood cells from artery to the vein.
Branching of blood vessels in the pulp; Shunts in the pulp.
For many years, investigators found it very difficult to establish the presence of lymphatics in the pulp;

Most believed there was no lymphatic drainage of the teeth. Tissue fluid was speculated to have drained back into the capillary or postcapillary sites of the blood vascular system;

In recent years a number of studies have demonstrated the presence of thin-walled, irregularly shaped lymphatic vessels;

They are larger than capillaries and have an incomplete basal lamina facilitating the resorption of tissue fluid and large macromolecules of the pulp matrix.
Hydrostatic pressure in dental pulp

Dental pulp interstitial fluid (ISF) and exchange of substances between plasma and ISF. (*values from Tonder and Kvinnsland, 1983; Ciucchi et al., 1995)
Inervation of the Dentin-Pulp Complex

- The dental pulp is innervated richly;
- Nerves enter the pulp through the apical foramen, along with afferent blood vessels, and together from neurovascular bundle;
- Once in the pulp chamber, the nerves generally follow the same course as the afferent vessels, beginning as large nerve bundles that arborize peripherally as they extend occlusally through the pulp core.
A cell-free zone is not present in developing teeth but becomes prominent in the coronal pulp after development;

The cell-rich zone lies immediately under the cell-free zone and contains numerous fibroblasts, macro-phages and capillaries;

The capillaries arise from arterioles (C) deeper in the pulp but are commonly found adjacent to, or even within, the odontoblast layer;

A large nerve bundle (B) is evident in this image forming part of the subondontoblastic plexus (of Raschkow).;

Nerve fibers pass from the plexus out toward the dentin. Occasionally a nerve fiber extends a short distance into the dentinal tubule with the odontoblast process. Pain is the only sensation carried from the pulp to the conscious level.
Plexus of Raschkow;

Ascending nerve trunks branch to form this plexus, which is situated beneath the odontoblast layer.
NERVE TRUNKS
The nerves extend to the periphery, where they form a plexus of nerves adjacent to the odontogenic zone above.
Nervous Tissue

Location: Brain; spinal cord; nerves
Function: Conduction of nerve impulses
PLEXUS OF RASCHKOW
There appears high organization of the peripheral pulp;

Top to bottom:
- Predentin;
- Odontoblasts;
- Cell-free and cell-rich zone;
- Parietal layer of nerves.
Intradentinal nerves are mostly found in pulpal horns.

Approx. 1800 non myelinated + 400 myelinated
Types and properties of pulpal sensory nerve fibers

A-beta fibers
- Conduction velocity 30-70 m/s;
- Very low threshold, non-noxious sensation;
- 50% of myelinated fibers in pulp;
- Functions not fully known.

A-delta fibers
- Conduction velocity 2-30 m/s;
- Lower threshold;
- Involved in fast, sharp pain;
- Stimulated by hydrodynamic stimuli;
- Sensitive to ischemia;
- Sharp pain.

C fibers
- Conduction velocity 0-2 m/s;
- Higher threshold;
- Involved in slow, dull pain;
- Stimulated by direct pulp damage;
- Sensitive to anesthetics;
- Dull pain.

Non-myelinated sympathetic fibers
- Conduction velocity 0-2 m/s;
- Post-ganglionic fibers of superior cervical ganglion;
- Vasoconstriction.
tooth pulp stained for nerve fibres, showing that it is an extremely densely innervated tissue.

A photomicrograph of human tooth pulp showing triple fluorescent labelling for nerves (green), blood vessels (blue) and immune cells (red).
ARTERY, VEIN, NERVE, AND FIBERS
- Most pulpal nerve endings are in the odonobogenic region of the pulp horns;
- Same terminate on or in association with the odontoblasts;
- Other are found in the predentinal tubules;
- These nerve endings are oresumed to function in pain reception.
It contains:

- glycoproteins;
- sialic acid;
- acid mucopolysaccharides;
- proteins bearing reactive $\epsilon$-amino groups of lysine-hydroxylysine.

The fibres and the ground substance are considered to interact forming coacervates.

The extracellular matrix is organized as a heterogeneous colloid containing soluble and insoluble fractions.

In young pulps the soluble fraction is large and the tissues are markedly affected by buffer solutions or enzymes.
Mucopolysaccharides or Glycosaminoglycans

- Hyaluronic acid;
- Heparin;
- Keratin sulfate;
- Chondroitin sulfate.
Hyaluronic acid is not sulfated and exists as free chains:

- Regulate the water exchange;
- Protective function - microbial hyaluronidase polymerized hyaluronic acid - thus forming a barrier to microorganisms;
- Retain water - protects odontoblasts and blood vessels;
- Regulates the transport of Na (sodium) and K (potassium).
They are present as constituent of proteoglycans, which consist of central protein core to which side chains of glycosaminoglycans are covalently linked;

The three-dimentional structure of proteoglycans can be portrayed as an interdental brush, with the wire stem representing the protein core and the bristles representing the glycosaminoglycans.
Because of the abundance of carboxyl groups, sulfated hexosamines, and hydroxyl groups in glycosaminoglycan chains, proteoglycans are intensely hydrophylic and act as polyanions;

The long chains form relatively rigid coils constituting a network in which a large amount of water is held;

Thus, proteoglycans are present as a characteristic gel that occupies a large space relative to their weight and provides protection against compression of connective tissue;

Given their spatial organization and high negative charge, proteoglycans prevent diffusion of larger molecules but attract cationic materials.
1. Inductive - induces the cells producing the dentin that surrounds and protects the pulp. The pulp also induces the enamel organ to become a particular type of tooth.

2. Formative - The pulp organ cells produce the dentin. The odontoblasts develop the organic matrix and function in its calcification. Through the development of the odontoblast processes dentin is formed along the tubule wall as well as at the pulp peridentin front.

3. Nutritive - The pulp nourishes the dentin through the odontoblasts and their processes.

The most important pulp function is to provide vitality to the teeth with its cells, blood vessels, and nerves;

4. Protective - The sensory nerves in the tooth respond with pain to all stimuli such as heat, cold, pressure, operative procedures and chemicals. The nerves also initial reflexes that central circulation in the pulp this sympathetic function is a reflex providing stimulation to visceral motor fibres terminating on the muscles of blood vessels.

5. Defensive - the pulp is an organ with remarkable restorative abilities. It responds to irritation whether mechanical, thermal, chemical or bacterial by producing reparative dentin and mineralizing any affected dentinal tubules.
Importantly, most extracellular matrix proteins and many growth factors such as transforming growth factors have binding sites for glycosaminoglycans;

Thus, proteoglycans regulate tissue organization by linking together several extracellular matrix components and may act as a reservoir for bioactive molecules.
During infection and inflammation, the high viscosity of proteoglycans may present a mechanical barrier to bacteria;

However, several bacterial species, such as some strains of streptococci, produce hyaluronidase as a spreading factor;

This enzyme reduces the viscosity of the barrier by hydrolizing glycosaminoglycans and thus contributes to bacterial penetration of connective tissues.
REGRESSIVE CHANGES IN THE PULP

REGRESSIVE CHANGES IN THE PULP AND SURROUNDING DENTIN ARE RELATED TO ENVIRONMENTAL STIMULI AND TO AGING.

As the tooth ages, pulp decreases in size because of the continued deposition of dentin. The decrease in size usually occurs because of uniform deposition around the entire perimeter of the pulpal border;

Pulpal cells decrease in general, as do cellular perinuclear cytoplasm and organelles in the cytoplasm, such as mitochondria and endoplasmatic reticulum - this indicates that cell activity has decreased;

Aging decreases the ability of the pulp to respond to injury and to repair itself.
PROTECTIVE FUNCTIONS OF THE PULP

- In its response to stimuli, such as heat, cold, pressure, and operative cutting procedures;
- The formation of sclerotic dentin;
- The process of mineral deposition in the tubules, originates in pulp and protect pulp from invasion of bacterial products.
REPARATIVE FUNCTION

- The pulp has the ability to be reparative through its response to operative cutting or dental caries by the formation of reparative dentin.
Pain is a function of the high concentration of nerve ending within the tooth;

Pulp is highly sensitive to temperature changes, electrical and chemical stimuli, and pressure;

The close relationship between nerve ending and odontoblasts and their processes is significant;

Moreover, the nerve endings in the dentinal tubules and the pulp may be some distance from where the pain is perceived, at the dentinoenamel junction and the inner enamel.
SEVERAL THEORIES ATTEMPT TO EXPLAIN THIS PHENOMENON:

- **Direct innervation theory**, which is based on the belief that nerves extend to the dentinoenamel junction (studies have not shown nerves present at the junction);

- **Transduction theory** - the odontoblastic process is the receptor and that it conducts the pain to nerve endings in the peripheral pulp and in the dentinal tubules;

- **Hydrodynamic theory** - was developed to explain the transmission of pain through the thickness of dentin - when dentin is stimulated, fluid and the odontoblastic process move within the tubules, making contact with the nerve endings in the inner dentin and adjacent pulp.
A. DIRECT INNERRATION THEORY;  
B. TRANSDUCTION THEORY;  
C. HYDRODYNAMIC THEORY
FIBROUS CHANGES

- One characteristic of aging is an increase in collagen fibers, which become more evident with the decreasing size of the pulp.
- Pulp stones are not always free within the pulp;
- They may become embedded in secondary dentin as this material proliferates out into the pulp cavity;
- An embedded pulp stone (A) lies near the center of the field;
- There is some suggestion of dentinal tubules (B) radiating from the center of the stone, true or false, so it may be classified as a true pulp stone;
- Pulp stones may also be classified as free, attached, or embedded.
In the center of the field, lying within the pulp (A), is a large spherical mass staining similar to the dentin (B) above;

- This is a pulp stone (C) or denticle;

- Pulp stones are mineralized masses that arise in the pulp and are classified as true or false;

- True pulp stones appear to be composed of dentin in that they exhibit dentinal tubules;

- False pulp stones do not appear to be produced by odontoblasts and are thought to originate from a mineralized nucleus in the pulp and grow appositionally;

*True pulp stones are rare.* Based on its morphology, this is a false pulp stone.