CHAPTER II

REVIEW OF THE LITERATURE

The review is divided into four major parts as follows: Dentin, Dentinal tubule, Dentin permeability, Dental impression material.

2.1 Dentin

2.1.1 Dentinogenesis

Dentin, a part of a tooth, is formed by odontoblasts which originate from ectomesenchymal cells of the dental papilla. The dental papilla cells which come from the inner enamel epithelium are small, undifferentiated and exhibit a central nucleus, few organelles and a central nucleus. Acellular zone of dental papilla are separated from inner enamel epithelium. They adjoin ectomesenchymal cells and rapidly enlarge and elongate to become preodontoblast, immediately after inner enamel epithelium reverse polarity. Preodontoblasts become odontoblasts after protein synthesizing organelles in their cytoplasm increase, the odontoblast differentiate and increase in size and occupy the acellular zone (Ten Cate, 2008).

The organic matrix of dentin forms after the differentiation of odontoblast. Von Korff's fibers (Figure 1), distrinct large diameter collagen fibrils, are the first dentin collagens which synthesized by odontoblast and deposit in the ground substance of the dental papilla (Figure 2 and 3). These fibers consist mainly of collagen fiber type III. They extend toward the inner enamel epithelium, and fan out in the structureless

ground substance immediately below the epithelium. While odontoblasts continue increase in their size, they produce smaller collagen type I, which arrange themselves parallel to the future dentinoenamel junction, conduce toward the mantle predentin layer (odontogenic zone) (Figure 4) (Rensburg, 1995). As the odontoblast moves away toward the pulp, the odontoblast process or Tomes' fiber is developed (Ten Cate, 2008).

Figure 1 Transmission electron micrograph shows a von Korff's fiber extends between two odontoblast cell bodies (Ten Cate, 2008).

Figure 2 Electron micrographs show the first collagen fibers (collagen); matrix vesicle (mv); enamel epithelium; basal lamina (Ten Cate, 2008)

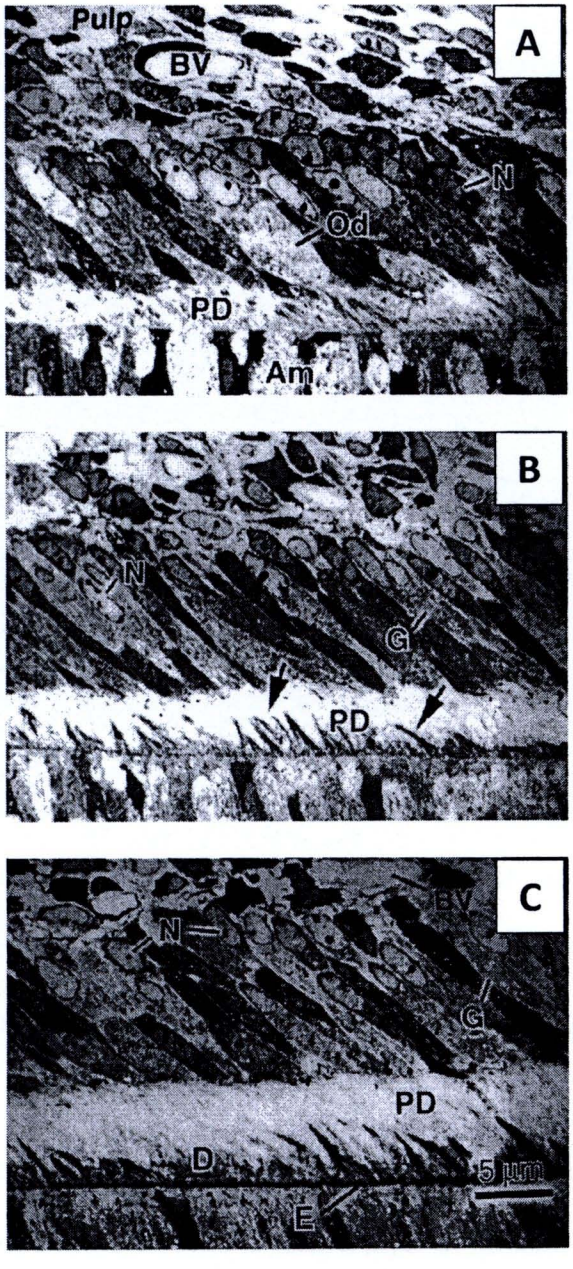

Figure 3 Low magnification micrographs show odontoblast arrangement as a palisade (A); the formation of predentin and the enlargement of collagen fibrils (arrow) to form predentin (B); the combination of fibrils to form mantle dentin (C). Blood vessel (BV); Odontoblast (Ob); Nucleus (Nu); Predentin (PD); Ameloblast (Am); Golgi complex (G); Dentin (D); Enamel (E) (Ten Cate, 2008)

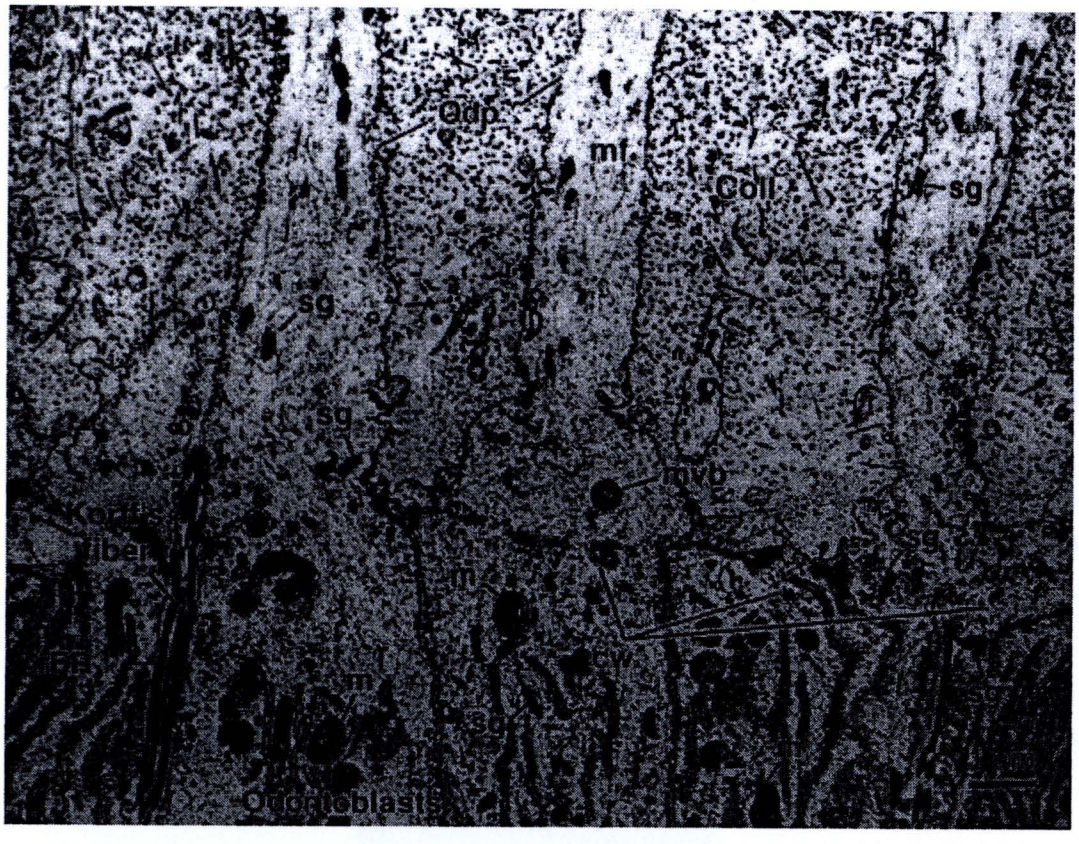

Figure 4 Transmission Electron Micrograph shows small collagen fibril (Coll); microfilament (mf); multivesicular bodies (mvb); elongated secretory granules (sg); mitochondria (m); rough endoplasmic reticulum (rER) (Ten Cate, 2008)

The crystals increase rapidly and rupture from the vesicles, form a cluster of crystallites and fuse with others clusters to form a layer of mineralized matrix. Later, the coronal mantle dentin is formed. The thickness of this layer is approximate 15 to 20 μm (Ten Cate, 2008). While dentin increase its thickness, the matrix fibers arrange their long axis more transversely and set to form thicker collagen bundles, so called circumpulpal dentin. During mineralization process, the dentinal tubules and odontoblast process develop and extend from odontoblastic cell bodies in the peripheral pulp toward the dentinoenamel junction. The odontoblastic cell bodies

then change to pear shape and line up like pseudostratified layer. The odontogenic zone next to the pulp or predentin, a lifelong unmineralized dentin layer, locates between the odontoblast cell bodies and mineralized dentin. This predentin is always present since the mineralization is deposit lag behind the formation of the matrix. Mineralization starts from the cusp of the crown. The conical addition of the mineral from the crown to the root results in the formation of incremental lines. The calcospherite, an inorganic material in fully mineralized dentin, usually homogenously coalesce, however interglobular space can occur when the combination of calcospherite is incomplete (Figure 5) (Rensburg, 1995).

Figure 5 The microradiograph picture shows interglobular dentin (Mjor and Pindborg, 1973).

During dentinogenesis, the capillaries initially are found during the formation of mantle dentin. They locate in the subodontoblastic layer and migrate between the odontoblasts (Figure 6) (Ten Cate, 2008).

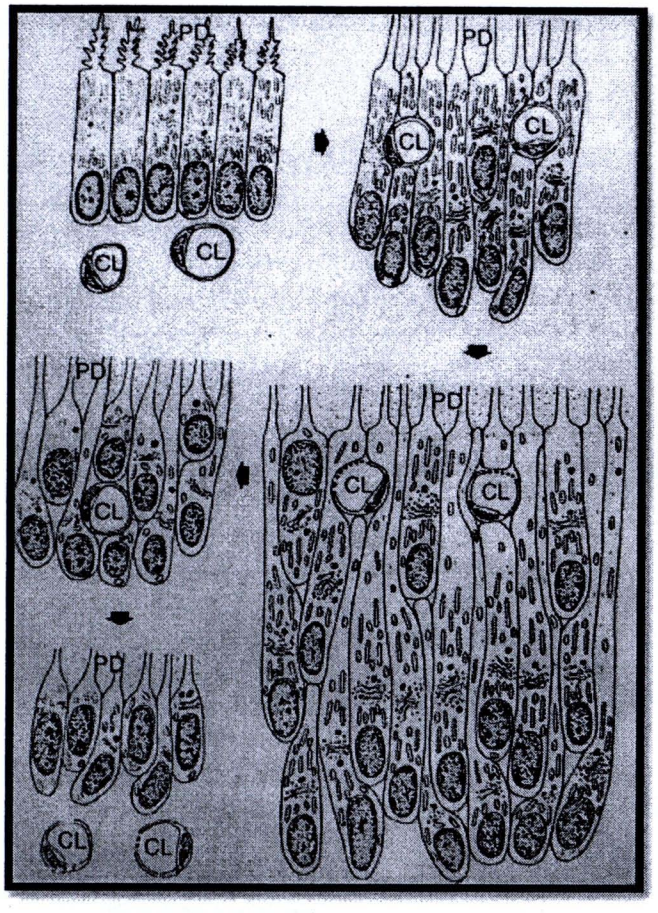

Figure 6 The diagram shows the changing of odontoblasts and capillaries in the dentinogenesis process. Predentin (PD); Capillaries (CL) (Ten Cate, 2008)

Total development of dentin, early and later development of dentin are showed in Figure 7, 8 (Rensburg, 1995).

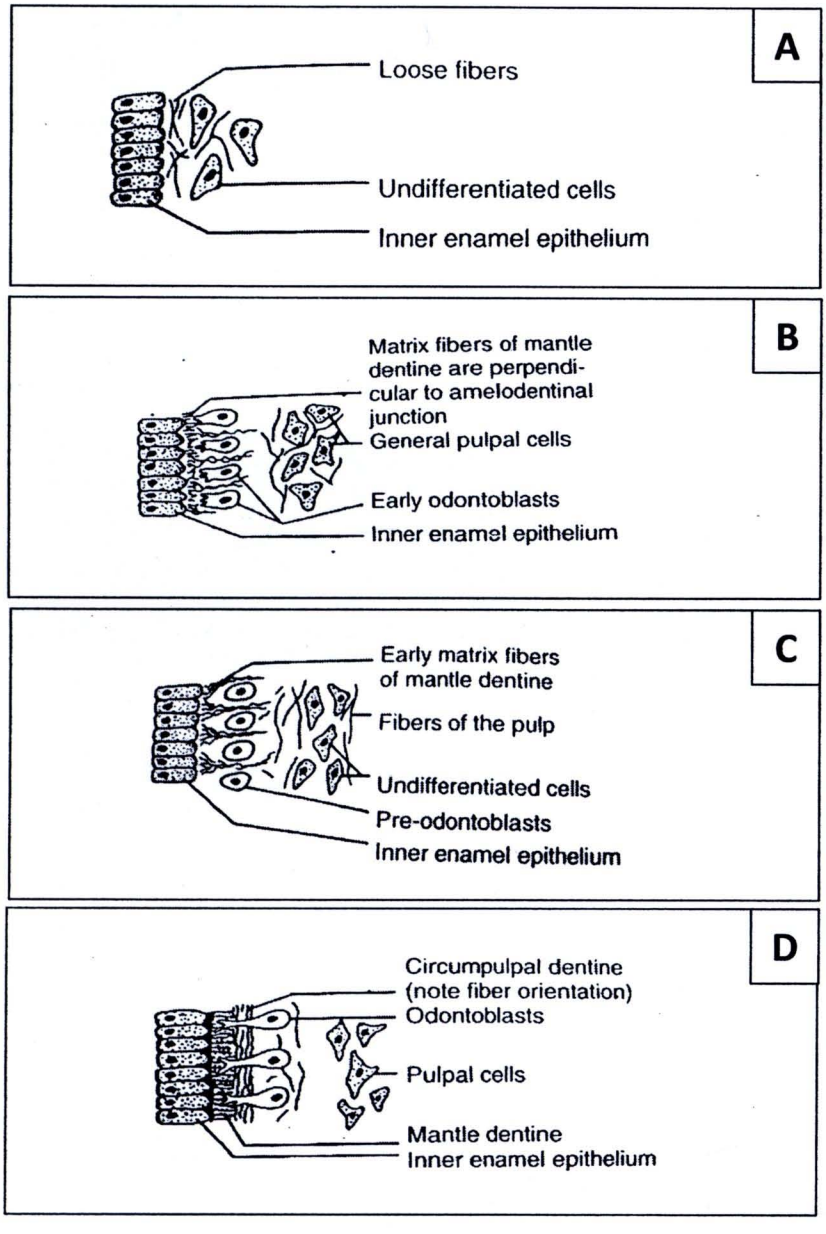

Figure 7 show early development of dentin; undiffentiated mesenchymal cell of dental papilla (A); preodontoblast (B); odontoblast (C); matrix formation (D) (Rensburg, 1995)

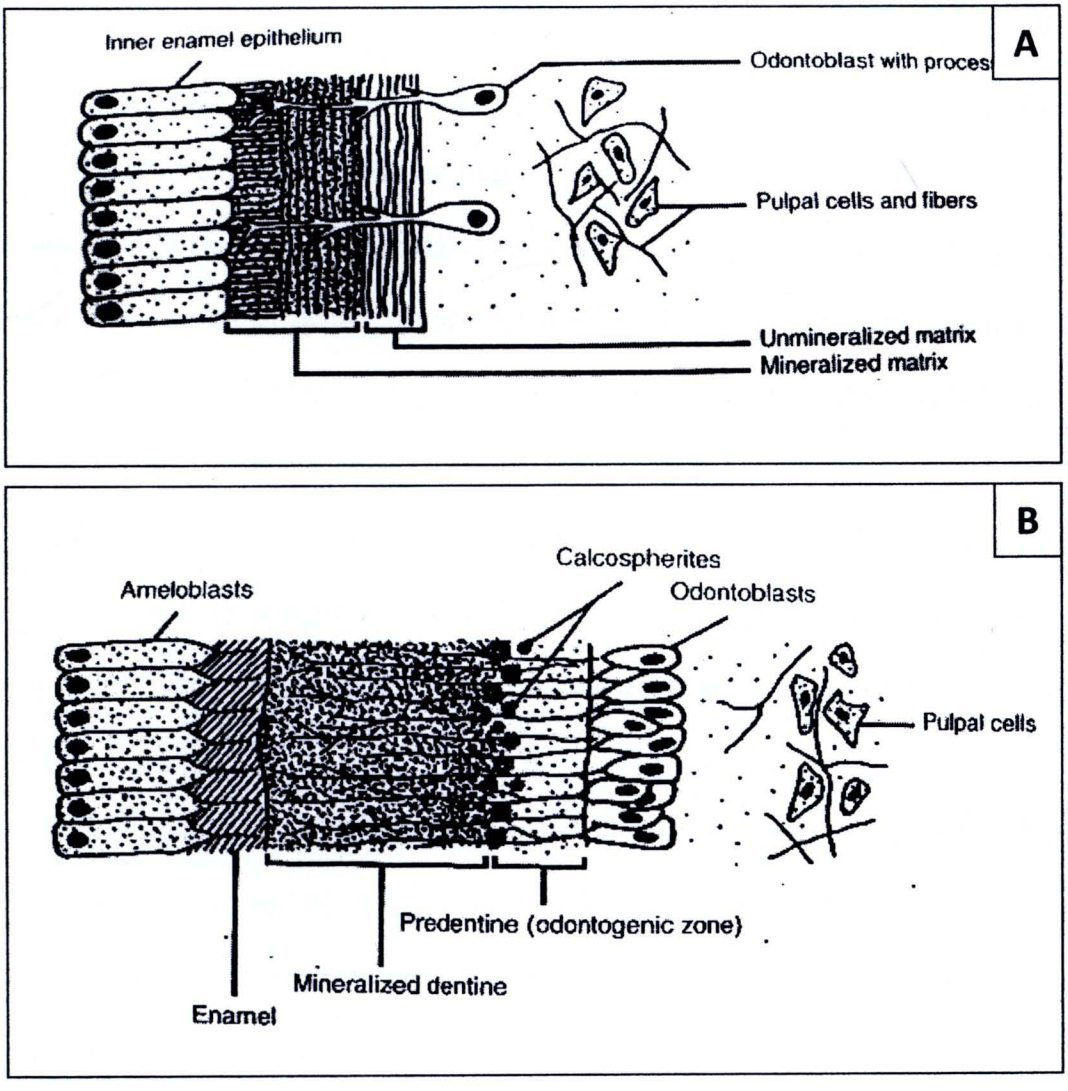

Figure 8 show late development of dentin; matrix formation and mineralization state (A); mineralization state (B) (Rensburg, 1995)

2.1.2 Structure of dentin

Dentin is a hard tissue which is composed of many dentinal tubueles and odontoblast processes. The cell bodies of the odontoblasts are the inner portion of the dentin that against a predentin and form the peripheral boundary of the pulp. The first deposition of dentin is predentin, a layer of unmineralized matrix (between mineralized dentin and odontoblastic layer) (Mjor and Pindborg, 1973). Predentin

consists particularly of collagen, it stains in hematoxylin-eosin less intensely than mineralized dentin so it is easy to identify. Predentin gradually mineralized and are incorporated at the mineralization front. The predentin thickness, 10 to 50μm, remains constant because of the balancing of the calcification. In newly erupted teeth, there are two zones of dentin which are closed to the pulp. The first dentin zone, adjacents to the predentin, has normal degree of mineralization. The second dentin zone, adjacent to the intertubular dentin and peritubular dentin, has low mineralization (Mjor, 1985). Mature dentin consists of 10% water, 20% organic matrix, and 70% inorganic matrix by weight and 22%, 33%, and 45% by volume respectively (Ten Cate, 2008). The element of dentin will vary upon the tooth age (Mjor and Pindborg, 1973).

The inorganic material mainly consists of small hydroxyapatite plates ($Ca_{10}(PO_4)_6(OH)_2$) (Mjor and Pindborg, 1973; Rensburg, 1995; Ten Cate, 2008). They are needle-shaped in the edge and plate-like in shape (Mjor and Pindborg, 1973). The hydroxyapatite crystal is approximately 50-60 nm in length but may be as long as 100 nm, somewhat less in width and the thickness may be up to 3.5 nm. Some crystals were found in the collagen fibers, mainly along the fibers (Rensburg, 1995). The crystals are smaller than those in enamel but similar to those in bone and cementum (Mjor and Pindborg, 1973). The other inorganic component is carbonates, calcium phosphates, sulfates and some elements such as F, Zn, Cu, Fe and others (Johansen, 1964). The fluoroapatite may be formed by replacing the OH groups in the hydroxyapatite with F^- ion (Mjor and Pindborg, 1973). The fluoroapatite is important in clinic because it is more soluble than hydroxyapatite. The organic material composed of collagen about 93 % of the total organic portion (mainly type I collagen,

about 56 %) with small amounts of noncollagenous matrix proteins, phospholipids and growth factors (Mjor and Pindborg, 1973; D'Souza, 2002; Garant, 2003; Ten Cate, 2008). The other 44% collagens of dentin matrix are collagen type III, V and VI (Garant, 2003). The main procollagen is secreted from the predentinal part of the odontoblast process (Garant, 2003). The periphery of dentinal tubules and collagen fibrils have noncollagenous matrix proteins that regulate mineral deposition (Ten Cate, 2008). The noncollagenous matrix proteins composed of dentin phosphophoryns (DPPs), proteoglycans, dentin glycoproteins (DGP), osteonectin, osteopontin, dentin matrix protein-1 (DMP1), dentin sialoprotein (DSP), osteocalcin, matrix extracellular phosphoglycoprotein, bone sialoprotein (BSP) and some serum proteins (Ten Cate, 2008). The DPPs, the major components of noncollagenous matrix proteins, are secreted from odontoblast process (Garant, 2003). Dentin phosphophoryns are templates for calcium and phosphate deposition (Stetler-Stevenson and Veis, 1987; Garant, 2003). During mineralization the predentin proteoglycans might regulated the timing and site of formation but some proteoglycans may inhibit mineralization of dentin (Garant, 2003).

2.1.3 Types of dentin

There are 3 types of dentin; primary dentin, secondary dentin and tertiary dentin (Ten Cate, 2008). Primary dentin, the most of dentin (Ten Cate, 2008), starts forming during the odontogenesis (Mjor, 2009). Its'outer layer, mantle dentin is formed from collagen fibers in a ground substance (Rensburg, 1995) prior to the eruption and completion of the apical region of the tooth (Smith, 2002). Mantle dentin is produced 4 to 8 μm per day (Garant, 2003). Secondary dentin is form after the completed root

formation (Smith, 2002; Ten Cate, 2008). The forming rate of this layer is 1 to 2 μm per day (Garant, 2003). Both primary dentin and secondary dentin are synthesized from the same odontoblasts (Smith, 2002). The differentiation between primary dentin and secondary dentin are primary dentin is harder and has more regular organization of dentinal tubules than secondary dentin (Garant, 2003; Ten Cate, 2008). It deposits high quantity on the roof and floor of pulp chamber (Smith, 2002). Tertiary dentin forms when dentin is stimulated by external stimuli such as dental caries, cavity preparation and restorative procedures as a response to localized injury for protect the pulp (Figure 9) (Smith, 2002; Garant, 2003). It can be separated in two subclassification as either reactionary dentin or reparative dentin (Smith, 2002). The reparative dentin formation is deposited by odontoblast-like cells and dentin matrix of the reactionary dentin is secreted by preexisting odontoblasts (Garant, 2003).

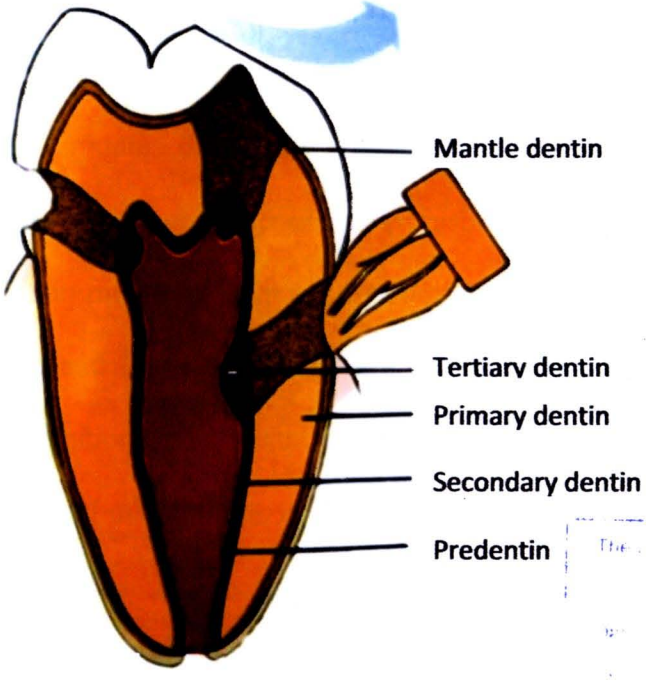

Figure 9 Terminology and distribution of dentin (Ten Cate, 2008)

2.1.4 Components of dentin

During the early stage of odontoblast development, the mantle dentin, which is the outer layer of dentin and adjacent to the enamel, deposits (Mjor, 1985; Garant, 2003). Mantle dentin is less mineralized than other dentin (Mjor, 1985). Next to the mantle dentin toward the pulp, the circumpulpal dentin, is the major portion of dentin where the odontoblast process appears (Garant, 2003). This dentin consists of intertubular dentin and peritubular dentin surrounding the dentinal tubule (Garant, 2003). The fibers of mantle dentin perpendicular to the dentinoenamel junction, in contrast to the fibers in circumpulpal dentin which is parallel (Mjor and Pindborg, 1973) There are serum proteins, including fibrinogen, albumin, and immunoglobulins in dentinal fluid of dentinal tubules (Garant, 2003). Dentinal fluid flow increases during dental operation and/or pulpal inflammation. Immunoglobulin levels increase in tooth with dental caries. Dentinal tubules are wider toward the pulp and more concentrated in the regions of the pulp horn. They extend from the mantle dentin to the predentin. The inner dentin (dentin nears the pulp) has approximately 65,000 tubules/m^2, the middle dentin has average 35,000 tubules/m^2 and approximately 15,000 tubules/m^2 in the outer dentin. (Rensburg, 1995)

The odontoblast is in the dental pulp and its odontoblast process extends into the dentinal tubule (Mjor and Pindborg, 1973; Ten Cate, 2008). The number of odontoblasts varies with location in the dental pulp space and tooth type (Ten Cate, 2008). There is the number of odontoblasts in coronal dentin more than those in root dentin. The number of odontoblasts in coronal dentin is about 59,000 to 76,000 per square millimeter. In fully developed tooth, the shape of cell bodies of odontoblasts are columnar at the coronal part of the dental pulp, cuboid at the midportion of the

dental pulp and flat at the apical part of the pulp. The morphology of odontoblast varies with the functional state of it. The basal nucleuses and the odontoblast cell appear elongated in secretory state. It has prominent organelles which consist of much endoplasmic reticulum, Golgi complex and mitrocondia. In transitional state, the nucleus from the basal of odontoblastic cell displaced apically. The endoplasmic reticulum is reduced and condensed chromatin is shown. In resting state, the odontoblast is narrower cell, the nucleus displaces apically, there are fewer cytoplasmic organells and secretory granules are reduced.

Odontoblast process has no major organelles but rich of microtubules and microfilaments which form a network and are oriented parallel to their long axis (Ten Cate, 2008). The branches of odontoblast process contain only fine filament which can penetrate through the sheath (stand during odontoblast process and peritubular dentin) and might join with the adjacent braches (Garant, 2003). The odontoblast process may extend to the dentinoenamel junction or cementodentinal junction. The root dentin has more numerous and smaller odontoblast process than those in the crown dentin (Mjor and Pindborg, 1973). There is periodontoblastic space between odontoblast process and the dentinal tubule wall which has tissue fluid and collagen fibers. This space has tissue changes and forms the soft tissue of the dentin (Mjor and Pindborg, 1973). It transports the components for the mineralization of peritubular dentin (Mjor, 2009).

Circumpulpal dentin composes of intertubular dentin and peritubular dentin (Garant, 2003). The intertubular dentin, the dentin between tubules (Ten Cate, 2008) or around peritubular dentin (Mjor and Pindborg, 1973), is the major component of the circumpulpal dentin. Collagen type 1 is the major collagen of intertubular dentin

(Garant, 2003). The collagen fibrils of intertubular dentin have hydroxyapatite crystals formed in and around them. Hydroxyapatite crystals are about 40 nm in length. The peritubular dentin or intratubular dentin is the minor component of the circumpulpal dentin (Garant, 2003). It locates around the odontoblast process (delimites the dentinal tubule (Ten Cate, 2008)). The peritubular dentin is located far 60-100μm from predentin-dentin junction and is not found in predentin (Rensburg, 1995). The inner peritubular dentin (near the pulp) is narrower than the outer peritubular dentin (at dentinoenamel junction) (Atkinson and Harcourt, 1961). This dentin has 40% more mineralized than intertubular dentin (Ten Cate, 2008). The hydroxyapatite crystals are smaller than those of intertubular dentin. The peritubular dentin doesn't have collagen fibrils but is rich in glycosaminoglycans (Figure 10). It has more susceptible to demineralization and degeneration during the caries process and has mild resistance to acid etching (Isokawa *et al.*, 1970; Garant, 2003) (Figure 11). An inner hypomineralized layer of peritubular dentin (near the dentinal tubule) is greater insolubility than an outer hypermineralized layer (Isokawa *et al.*, 1970). Hirayama (1985) reported that no different of calcium and phosphate contents between peritubular and intertubular dentin. The peritubular dentin of a primary tooth was wider than permanent tooth 2-5 times.

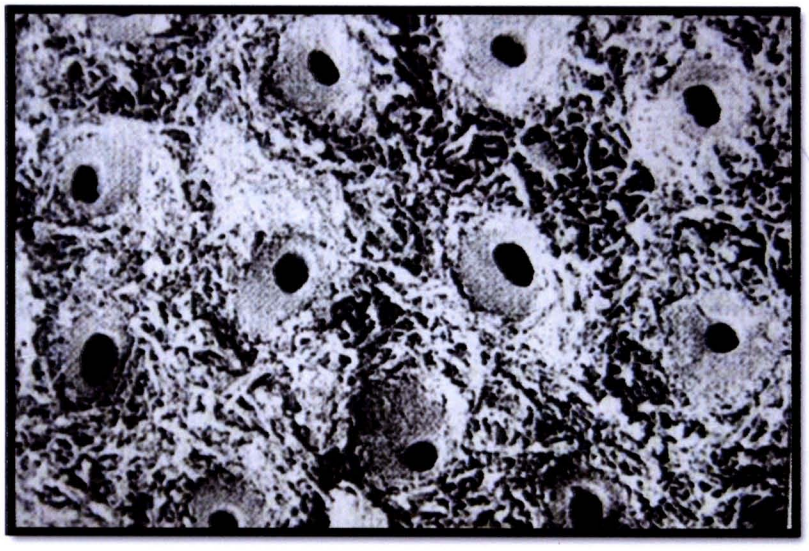

Figure 10 Scanning Electron Micrograph show dentinal tubule, peritubular dentin (a nonfibrillar appearance), intertubular dentin (a fibrillar appearance) (Smith, 2002)

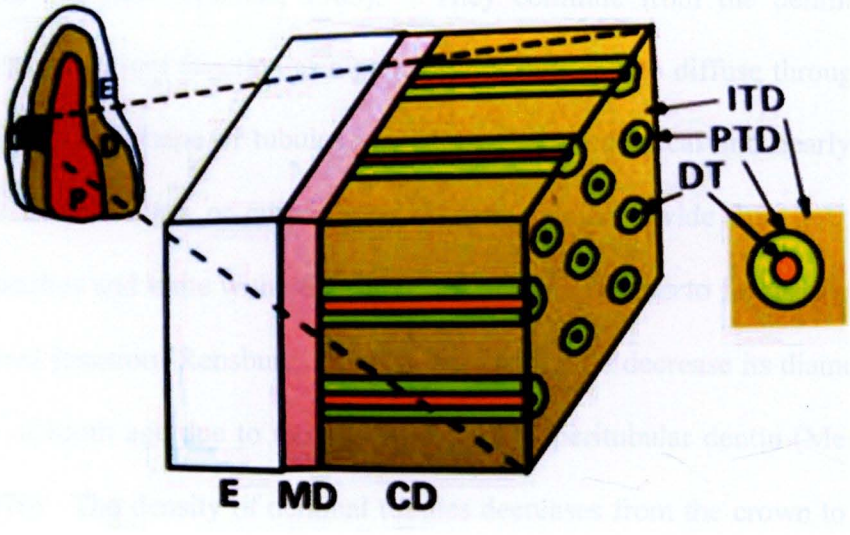

Figure 11 The cross sectional section of the tooth shows dentinal tubule (DT); peritubular dentin (PTD); intertubular dentin (ITD); mantle dentin (MD); enamel (E) (Garant, 2003).

A barrier of dentin is a tight junction which regulates the movement of fluids (nerves are extremely sensitive when the fluid around them (Orchardson, 1978)) (Bishop and Yoshida, 1992). It is permeable to water and small ion and impermeable to larger metallic ion (Orchardson, 1978; Bishop and Yoshida, 1992; Knutsson et al., 1994). The fluid may passes through the odontoblasts layer by transcellular or intercellular or both (Bishop and Yoshida, 1992). This barrier facilitates dentin matrix and subsequent mineralination. It helps to protect the pulp from bacteria from caries lesions or toxic material from the base of restorations (Orchardson and Cadden, 2001).

2.2 Dentinal tubule

Predentin matrix deposited and mineralized around the odontoblast processes to form dentinal tubules (Thomas, 1985). They continue from the dentinoenamel junction to the pulp and function as a pathway for nutrients to diffuse through dentin (Smith, 2002). The shape of tubules is shallow S-shaped apical and nearly straight beneath the incisal edges or cusps. The dentinal tubules divide into few or more terminal branches and unite with other branches of other tubules to form a plexus near dentinoenamel junction (Rensburg, 1995). Dentinal tubule decrease its diameter with an increase of tooth age due to the mineralization of peritubular dentin (Mendis and Darling, 1979). The density of dentinal tubules decreases from the crown to the root apex (Carrigan *et al.*, 1984).

2.2.1 Dentinal tubule in primary tooth

Sumikawa *et al.* (1999) studied primary maxillary anterior teeth with full root development. They reported a variation of tubule diameter of primary canines and lateral incisors from 1.39 to 1.94μm which were greater than that of permanent dentin. The tubule diameter of lateral incisors was greater than the canines. Both lateral incisor and canine show the dentinal tubules diameter increase from the dentinoenamel junction toward the pulp. The peritubular dentin width decreases at a similar rate as the increase of tubule diameters.

The average numerical tubule density increase from the dentinoenamel junction to the pulp (Sumikawa *et al.*, 1999). The numerical tubule density in lateral incisors was greater than that in the canines. The numerical tubule density in solid dentin is greater than that of permanent teeth. Due to the primary dentin has larger tubules diameters and peritubular dentin at least as thick as permanent dentin, the solid dentin available for bonding is decreased after acid etching.

However, Koutsi *et al.* (1994) reported a controversy study. They found that the density and diameter of the dentinal tubules in primary molars were lower and smaller than the values of permanent dentin. The tubule diameter is range from 1.13 to 1.39 μm, 1.00 to 1.20 μm, 0.89 to 1.17 μm and 0.97 to 0.99 μm at a distance of 0-30%, 30.1-60%, 60.1-90% and 90-100% from the pulp respectively. The number of tubules is approximate 18,816 to 36,650, 16,794 to 22,782, 15,266 to 21,132 and 17,335 to 18,530 per square millimeter at a distance of 0-30%, 30.1-60%, 60.1-90% and 90-100% from the pulp respectively. The permeability of the primary molars was lower than premolar and increase when remove the smear layer. This was due to the primary molars were nearly exfoliate and the deposition of additional peritubular

dentin matrix. The authors reported that the density and the size (diameter) of the tubules in primary molars increase toward the pulp. The tubules, the routes for pass the substances to and from the pulp, are taper from the pulp outwards. Hirayama *et al.* (1985) reported that the tubule of primary dentin had smaller diameters than permanent dentin due to its wider peritubular dentin.

2.2.2 Dentinal tubule in permanent tooth

Garberoglio and Brannstrom (1976) reported the number of tubules and tubule diameter of human permanent teeth as show in Table 1. The number of tubules is widely variant, possible due to distance measurements error and the variation between individual teeth. Dentinal tubules are about 10% by dentin volume, with the higher percentages in the dentin nearby the pulp.

Table 1 Show the number of dentinal tubules and tubule diameter of permanent tooth at various distance from the pulp (Garberoglio and Brannstrom, 1976)

Distance from the pulp (mm)	Number of tubules (1000/mm2)		Tubule diameter (μm)	
	mean	range	mean	range
Pulpal wall	45	30-52	2. 5	2. 0-3. 2
0. 1-0. 5	43	22-59	1. 9	1. 0-2. 3
0. 6-1. 0	38	16-47	1. 6	1. 0-1. 6
1. 1-1. 5	38	21-47	1. 2	0. 9-1. 5
1. 6-2. 0	30	12-47	1. 1	0. 8-1. 6
2. 1-2. 5	23	11-36	0. 9	0. 6-1. 3
2. 6-3. 0	20	7-40	0. 8	0. 5-1. 4
3. 1-3. 5	19	10-25	0. 8	0. 5-1. 2

The tubule densities of premolar were reported by Fosse and colleague (1992). Teeth were taken from patients aged 10-14 years, and cut axiobuccolingually and slightly lateral to the longitudinal axis to the depth of 0.3 mm from the pulpal wall. The average value was 51,368 per square millimeter. Cate (2008) reported the numbers of tubules that are approximate 59,000 to76,000 tubules/mm^2 at the pulpal surface of cervical parts of young premolar and molar teeth and are approximate

reduction to half near the enamel. The dentinal tubules diameter is approximate 2.5 μm near the pulp and 900 nm near the dentinoenamel junction.

2.3 Dentin permeability

Permeability, in physic, means the ease of transit and/or the diffusion rate through a tissue under standard agreement (Mjor, 2009). It is the phase or quality of being open the transit, mainly ions, fluids, bacteria and microscopic particles. The factors that influence the transition are the received pressure, the structure, the chemistry and the thickness of the involved tissue and the exposed area. Radioactive isotope can use to test the dentin permeability but it may be redox indicators. Dentin permeability or dentinal fluid movement affect to dentin sensitivity of exposed dentin (Pashley, 1986). The increase of dentin permeability reflexes dentin sensitivity. The smear layer on dentin during restorative procedures, mineral from salivary or dentinal fluid, and adsorption of plasma protein to dentinal tubule, bacteria, proteoglycan, collagen fibril, calculus, intratubular deposition of mineral and the growth of peritubular dentin occlude the dentinal tubules result in the decrease of dentin permeability (Pashley, 1985; Pashley, 1986). The smear layer is small ground particles, saliva or liquid that smear on the prepare surface (Mjor, 2009). It called smear plug when it deposits into the dentinal tubules. A water spay cannot remove it but it can be removed quickly and easily by acid etching. Polishing the dentin surface with pumice can remove the smear layer but cannot remove the smear plug. When apply resin monomer and polymer on the dentin surface, they fill between the collagen mesh and form a hybrid layer which is an essential adhesive in dentistry (Figure 12). Normally, the coronal dentin which is covered by enamel and the

radicular dentin which is covered by cementum, are impermeability (Pashley, 1986). Pulpal fluid can diffuse toward the exposed dentin surface and oral fluid can diffuse toward dental pulp in sensitivity tooth. This movement is bidirection diffusion in the pulpal dentin complex. When this occlusion is absence, the exposed dentin teeth may sensitive which require therapies for example using dentin desensitizing agents, application unfilled resin or oxalate salts. These agents will occlude dentinal tubules. Pashley *et al.* (1986) studied the influence of plasma protein to dentin permeability. They concluded that plasma protein reduced dentin permeability. The painful stimulation of exposed dentin (cavity preparation) induced vasodilation, increased capillary permeability, increased plasma proteins from the pulp fluid, occluded dentinal tubule and decreased dentin permeability. In mandibular first molars of the dogs, dentin permeability was decreased immediately after cavity preparation (Pashley *et al.*, 1984). The mechanisms were unclear. Nevertheless, this phenomenon was the benefit for restoration, for example to permit calcium hydroxide dressing into the exposed dentinal tubules.

Acute and arrested caries have influence to the permeability of the dentin (Mjor, 2009). There is a demineralization of enamel and dentin in acute caries. There is the lost of mineralized salts and the appearance of porosities. Therefore, the permeability of dentin increases. Fracturing of the enamel over the superficial part of the acute caries and the changing in oral hygiene improve the self cleansing. Therefore, the acute caries changes to the arrested caries. The mineral salts in arrested caries occlude the dentinal tubules. The rhombohedra and needle shape of crystals are formed in arrested caries of tertiary dentin causing the decrease of dentin permeability.

The tertiary dentin is formed in the reaction of various stimuli, such as dental caries (Mjor, 2009). They formed by the different odontoblast to primary dentin and it is irregular in structure. Some tertiary dentin has atubular mineralization and effected on the permeability of dentin. It is the barrier for penetration in the dentin.

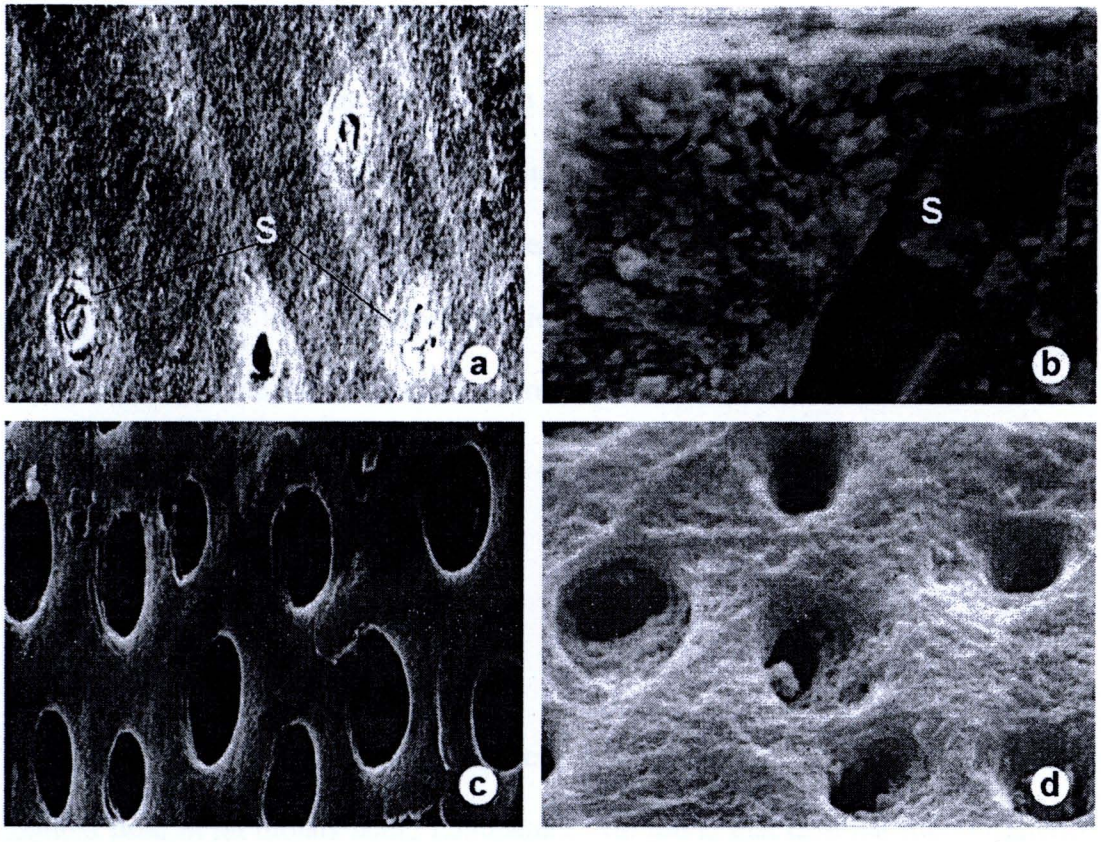

Figure 12 Scanning Electron Micrographs show a crown cross-sectioned preparation surface that was polished by pumice and clean with water spray. (a); a longitudinal dentinal tubule section has a smear plug (S) in it after cavity preparation (b); an 60 seconds acid etched dentin surface is washed and dried with a water spray and air syringe (c); collagen mesh remain in an 20 seconds acid etched and gently dry dentin surface (d) (Mjor, 2009)

Dentin permeability increases with the increase of tubule density and size. Nevertheless, the tubule diameter is more important than the densities (Pashley, 1985). Koutsi *et al.* (1994) found that the density and the size (diameter) of primary molar were lower than premolar, therefore dentin permeability in primary molar was lower than that in the premolar. Acid etching remove the smear layer leading to the increase of the dentin permeability (Pashley *et al.*, 1978). Outhwaite *et al.* reported that dentin permeability increased when dentin thickness from the dentinoenamel junction reduced, when dentin temperature increased and when the post extraction time was increased. However, the latter showed a little. Dentin sensitivity and permeability permit the permeation of microbial's products to dentinal tubules. The concentration of microbial's products increase when the dentin is thinner, the absence of a smear layer and high potency of the microbial (Outhwaite *et al.*, 1976; Pashley, 1985; Warfvinge *et al.*, 1985).

2.3.1 Fluid flow measurement

Dentinal fluid is in dentinal tubule (Tanaka, 1980). Tanaka (1980) studied dentinal fluid in rat molars using Lanthanum. He found that dentinal fluid originated from terminal capillaries in the pulp and penetrated into peritubular dentin and peri-odontoblast spaces of dentinal tubules but not into intertubular dentin. Several techniques have been used to measure the dentinal fluid flow. They will be mentioned as follow.

2.3.1.1 Hydraulic conductant (Lp)

Hydraulic conductant (Lp) is the one way to evaluate dentin permeability by fluid filtration method (Erturk and Kirzioglu, 2007). This classical system includes visual observation of the movement of an air bubble. The uses of direct visual reading and manually produce air bubbles made the system difficult for measurement. Therefore, a new electronic hydraulic conductant measurement system was added to the classical system. It consisted of oxygen pressure tank which produced 10 air pressures and has two air pressure regulators, a pressure reservoir and solenoid valves for producing an air bubble automatically and four photosensors for detecting the movement of the air bubble in the capillary tube and for calibrating the system. The photosensors, polyethylene tubes connecting pressure reservoir to capillary tube and capillary tube to split chamber device (Figure 13).

The hydraulic conductant of permanent teeth were significantly higher than primary teeth (Koutsi *et al.*, 1994). The tubular diameter of primary teeth was smaller than that from the permanent teeth and the peritubular dentin matrix of primary teeth were wider than permanent teeth. This report conflicted with the report of Sumikawa *et al.* (1999).

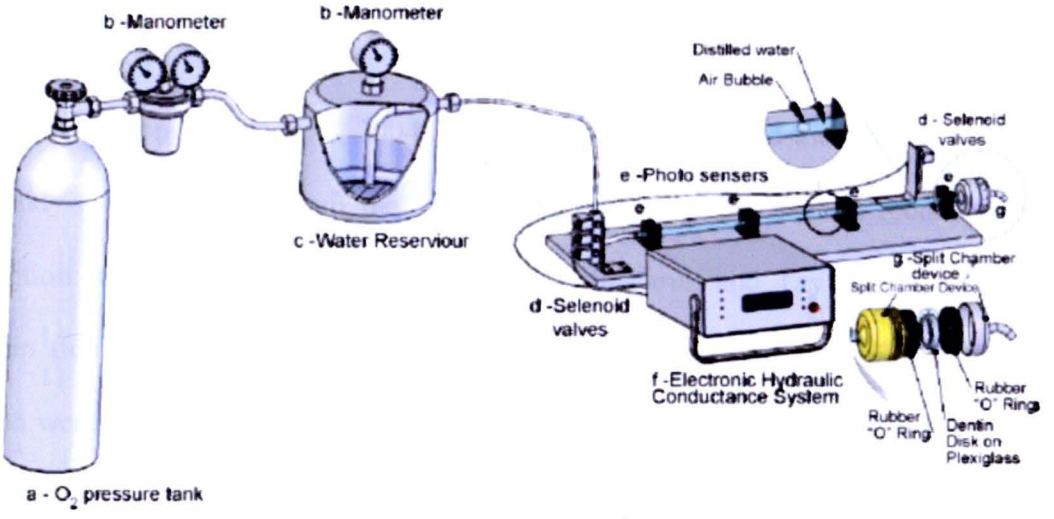

Figure 13 A schematic diagram of the electronic hydraulic conductance measurement system with photosensors (Erturk and Kirzioglu, 2007)

Vongsavan and Matthews (1992) studied fluid flow in cat dentin. They used hydraulic apparatus and measure the movement of the milk fat droplets in a glass capillary. Ciucchi *et al.* (1995) evaluated the pulpal pressure in human premolar teeth using hydraulic apparatus. The equipments compose of glass capillary tube that is mounted horizontally, an infrared beam that was pass by the tube and photosensitive receptor (detect an air bubble movement). They found that the mean value of pulpal tissue pressure was 14.1 cm H_2O. This technique is less sensitive to thermal effect however, the difficulty in setting up the complicated equipments and a needed of large preparation made it unsuitable to use in the clinic.

2.3.1.2 Replica technique

Replica technique is another technique to measure fluid flow from exposed dentin (Kerdvongbundit et al., 2004). Bharali *et al.* (1988) used the replica technique to study sweat droplets from the hind paw of the rat. This method records sweat secretion with a dental impression material. Itthagarun and Tay (2000) evaluated dentin fluid of anesthetized vital human permanent molars using replica technique. Teeth were separated into 2 groups: group 1 without vasoconstrictor and group 2 with vasoconstrictor. Fluid exudation was found in group 1 but not in group 2. The authors concluded that anesthetic containing vasoconstrictor caused the reduction of dentin fluid by reduced intrapulpal pressure and/or reversal pulpal flow direction. Kerdvongbundit *et al.* (2004) used the replica technique to study droplets from 24 human permanent molars. They found that the droplets were presented in unetched dentin more rapidly than etched dentin. Under the 30 mmHg pulp pressure above the atmospheric, droplets in unetched dentin were presented after 30 second (Figure 14). A hydrophobic silicone rubber material is used to record dentinal fluid from exposed dentin then replicated the impression with epoxy resin. This method is easy to set up the equipment and suitable to use in clinic.

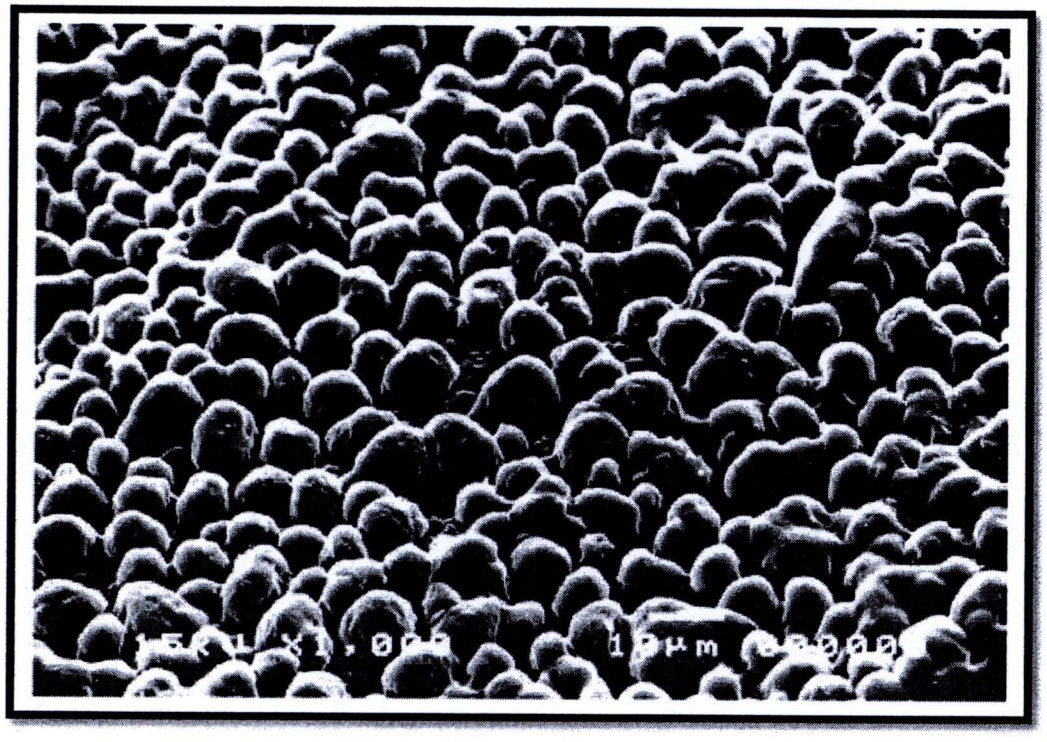

Figure 14 Scanning Electron Micrographs of replicas show unetched dentin surfaces in which the pulp pressure was set at 30 mmHg above atmospheric (Kerdvongbundit *et al.*, 2004).

2.4 Dental impression material

Dental impression material are used to record of oral structures (O'Brien, 1997). There are 2 states of impression materials; first is fluid or a plastic state, and second is elastic or non elastic which appears after polymerization. A model material, for example stone is poured in the impression and sets. It produces a final positive reproduction, called model or cast. There is a variety of impression materials but none are ideal for all applications (O'Brien, 1997; Power and Wataha, 2008). It is upon demand. The classification of impression materials are separated several ways as show in table 2 (Phillips, 1991). This review explains the classification according

to the elasticity of dental impression materials.

Table 2 Classification of impression materials (Phillips, 1991)

	Rigid or non elastic	**Elastic**
Set by chemical reaction (irreversible)	Zinc oxide eugenol	- Alginate hydrocolloid - Nonaqueous elastomers Polysulfide polymer Polyether Silicone - Condensation polymerization - Addition polymerization
Set by temperature change (reversible)	Compound	Agar hydrocolloid

2.4.1 A non elastic impression material

A non elastic impression material is rigid, thus cannot be applied with teeth which have undercuts (O'Brien, 1997; Power and Wataha, 2008). It is used with non undercut areas for examples edentulous area and a tooth that is prepared for a full crown. Impression plaster, dental impression compound (type I and type II), zinc oxide eugenol are non elastic impression materials. A non elastic impression material is used less frequently than an elastic impression material.

2.4.2 An elastic impression material

An elastic impression material is flexible (O'Brien, 1997; Power and Wataha, 2008). These materials include agar (reversible) hydrocolloid, alginate (irreversible) hydrocolloid, polysulfide rubber (mercaptan), additional (vinyl) silicone, polyether rubber and condensation silicone rubber.

2.4.2.1 Agar hydrocolloid

Agar hydrocolloid is the first successful elastic impression material (O'Brien, 1997; Power and Wataha, 2008). It is cheap, good smell, nontoxic and nonstaining. It is a hydrophilic and can displace body fluids. It eases for pouring and removing from the stone, however immediate pour is required. It can be used for only a single cast, requires expensive equipment and advance preparation. Therefore, it is soon replaced by rubber impression materials which have the greater dimension stability and give a better quality of gypsum models.

2.4.2.2 Alginate

Alginate is the most frequently used impression materials in dentistry. (O'Brien, 1997) It is cheap, good taste and easy to prepare. It is hydrophilic and can displace body fluids. It can be used with a stock tray however, need to be poured immediately after remove the impression from the mouth and can be used for only a single cast. Moreover, it does not give good details and has unstable dimensions.

2.4.2.3 Polysulfide rubber

Polysulfide rubber is cheaper than silicone and polyether. It gives good details, a

long working time, high flexibility, and good tear strength. (O'Brien, 1997) Nevertheless, it dose has a bad smell, low viscosity and staining the clothes.

2.4.2.4 Additional (vinyl) silicone

Vinyl silicone is expensive, high accuracy, hydrophilic, high dimensional stability and moderate tear strength (O'Brien, 1997). It can be removed easily after setting, does not stain clothing, and can be used with stock trays. Multiple casts can be poured from one impression however, immediate pouring is not allowed. It is difficult to remove this impression around undercuts. It releases hydrogen gas and produces bubbles on models after setting. Latex gloves can inhibit its polymerization.

2.4.2.5 Polyether rubber

Polyether rubber properties are high stiffness, short working time, available in low-medium and high viscosity. (O'Brien, 1997) It is not suitable for the severe undercut tooth but it is easy to pour. The other dimension stables for up to one week. The disadvantages of this material are high cost, bitter test, high stiffness and short working time.

2.4.2.6 Condensation silicone rubber

Condensation silicone rubber composes of a base and a catalyst (accelerator) (O'Brien, 1997; Power and Wataha, 2008). It commonly uses in the dental laboratory and should be poured within one hour after taking impression due to the dimentional change occurs 50% during the first hour after setting. This material has several properties include very hydrophobic, high elastic, very low viscosity, and vary setting

time upon the amount of catalyst. A putty wash system is used to improve the accuracy of the impression. The setting time is 6-8 minutes. The moisture and higher temperature shorten the setting time. This material is, therefore, selected to use in the study of replica technique (Kerdvongbundit *et al.*, 2004).

Table 3 Mechanical, physical and properties of elastic impression materials (Power and Wataha, 2008)

Property	**Additional silicone**	**Polyether**	**Condensation silicone**	**Polysulfide**
Working times	Short-moderate	Short	Short	Moderate-long
Setting time	Short-moderate	Short	Short-moderate	Moderate-long
Shrinkage on setting	Very low	Low	Moderate-high	High
Elastic recovery after removal	Very high	High	High	Moderate
Flexibility after removal	Low-moderate	Low-moderate	Moderate	High
Tear strength	Low-moderate	Moderate	Low-moderate	Moderate-high
Flow setting under small forces	Very low	Very low	Low	Moderate-high
Gas evolution after setting	Yes	No	No	No
Detail reproduction	Excellent	Excellent	Excellent	Excellent