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Age changes in dentin and its effect on bonding: A mini review

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Abstract
Objective: The objective of this mini review is to evaluate the age-related changes in dentin and its effect on bonding.
Background: Bonding to dentin poses a great challenge which can be attributed to multifarious including factors such as the high organic content of dentin, the presence of dentinal tubules, a continuously moist environment due to fluid presence in the tubules, permeability in dentin, and intratubular pressure. The bonding becomes more challenging with advancing age due to corresponding age-related changes. This dental problem triggered by age-related changes is mainly attributed to the mineralization property of dentin. The bonding to dentin differs significantly in both primary and secondary dentin. These differences can be maintained by altering the etching time.

Keywords: Dentin, restoration, permeability, bonding, age changes, composite

Introduction
Dentin is a mineralized connective tissue that comprises the bulk of teeth. It lies between the pulp chamber and the enamel/cementum. By nature, dentin is tough, resilient, and flexible, which prevents the fracture of enamel [1]. The dentin properties are altered due to age-related changes, chemical and mechanical external stimuli. Histologically, they are characterized by narrowing of the lumen of the dentinal tubule and tubular occlusion due to increased calcification. This increased deposition of calcium leads to a reduction in the amount of peritubular fluid and reduced sensitivity [2, 3]. Acid etching of the tooth alters permeability of dentinal tubules due to dissolution of peritubular dentin, eventually resulting in exposure of collagen fibrils of the intertubular dentin.
Resin composites are tooth-coloured materials that are used as restorations, pit and fissure sealants, cavity liners, and endodontic sealers. They are also used as bonding agents for veneers, crowns, and orthodontic devices. Resin composites are composed of two phases: an organic resin matrix and an inorganic/organic filler, and they both bond micromechanically to the tooth substrate. While the organic resin matrix phase is a mixture of both monomers and initiators, the inorganic/organic filler phase contains micro-/nanosized fillers, which are mainly used as reinforcement. The in-situ polymerization of the dental resin composite by light irradiation (in the blue region of the light spectrum) forms a highly crosslinked polymer network that restores the missing dentin/enamel structure [4, 5]. This review describes the changes in dentin due to ageing and its effect on bonding.

Dentin
Dentin is a specialized hard connective tissue to forms the bulk of the tooth, and is further characterized by the presence of cytoplasmic process within the substance of the dentin while its cell body is located at the pulp-dentin border. The prominent feature of the microstructure of dentin is the presence of dentinal tubules and the cytoplasmic processes that communicate with the external environment when it is exposed due to various causes.
Dentinal tubules are cylindrical canals of 1–2 µm in diameter, extending from the pulp to the dentinoenamel junction (DEJ) [6, 7]. Dentin is composed of an inorganic mineral phase (70%), an organic matrix (20%), and water (10%).

The inorganic component is made up of hydroxyapatite, calcium carbonate, sulphate, phosphate, and trace elements of copper, iron, zinc, and fluorine. The organic portion is composed of type I collagen, non-collagenous matrix proteins (phosphoproteins, glycoproteins, proteoglycans), enzymes (acid phosphatase, alkaline phosphatase), and lipids (phospholipids, glycolipids) [8, 9].

Although essentially dentin is formed throughout the life of a human tooth (Fig 1), it has been physiologically classified as primary and secondary dentin on the basis of their spatiotemporal formation while the formation of tertiary dentin is stimulus induced. Together, they are referred to as circumpulpal dentin while mantle dentin is the initial dentin matrix proteins secreted into the preformed collagen fibres. Histologically, dentin is segregated as intertubular and peritubular on the basis of their location with reference to the cytoplasmic processes. The intertubular dentin occupies a large volume of the primary dentin and is formed by the secretory products of odontoblasts during dentinogenesis. Peritubular dentin immediately surrounds the dentinal tubules. By its growth, it constricts the dentinal tubules to a diameter of 1µm near the dentinoenamel junction. The organic matrix is lost along with mineral after decalcification [10].

Dentinal tubules

Physically and chemically, the dentin closely resembles a bone. The main difference between the bone and the dentin is that some of the osteoblasts are present on the surface of the bone, and when one of these cells becomes enclosed within its matrix, it is called an osteocyte. Mammalian odontoblasts exhibit terminal polarization, with cell bodies present outside the predentin/dentin layer at the periphery of the pulp. The cell bodies cross the predentin and extend inside dentin tubules up to the dentin–enamel junction. This arrangement is not vascularized and is termed as orthodentin [8, 9, 11].

Dentinal tubules contain cytoplasmic processes that extend from the DEJ in the crown, or the dentinocemental junction (DCJ) in the root, to the pulp. The tubules are S-shaped from the outer surface of the dentin to the area nearest the pulp [8, 9, 12]. In the dentin immediately beneath the enamel (within 0.3 mm), the tips of the tubules twist or curl, occasionally even up to 90 degrees. But at a level of 0.5 mm into dentin, the tilting or curling of the tubules does not take place due to odontoblast crowding. The dentinal tubules exhibit numerous branches, which are classified into major, fine, and microbranches. Major branches (0.5-1.0 mm diameter) are numerous and are present peripherally, fine branches (300-700 nm diameter) are extensively present where the density of tubules is relatively low, and the microbranches (25-200 nm diameter) are present at right angles to the tubules in all parts of the dentin [12]. The number of tubules amounts to about 45,000/mm^2 close to the pulp to about 20,000/mm^2 near the DEJ. The average tubule diameter lies in the range between 0.63 µm at the periphery and 2.37 µm near the pulp. The tubules occupy 1% of the total surface near the DEJ and 22% of the surface area close to the pulp [13, 14].

Ponce *et al*. observed that the numerical densities of dentin tubules were 21,000/mm2 at the crown–root junction, 15,000/mm2 at the cervical-middle, and 13,000/ mm^2 at the middle-apical thirds of the root[15]. Lo Giudice *et al*. reported that the average number of dentinal tubules in the middle zone was lesser, when compared to the coronal and the apical zones [7].

Dentinal fluid is a transudate of the extracellular fluid that contains proteins and immunoglobulins. The protein concentration is one fifth of plasma. Since it is a plasma-derived fluid, it also contains inflammatory mediators including cytokines, chemokines, and defensins [16]. The amount of dentinal fluid differs by depth, and the dentin close to the pulp contains more fluid compared to the superficial dentin [17].

Exposure of the pulp–dentin complex causes an outward flow of the dentinal fluid, thereby protecting the pulp. This outward flow of the dentinal fluid results in blockage of the tubules, with subsequent dental sclerosis. The dentinal fluid exhibits polymorphonuclear leukocytes, B cells, T cells, and macrophages that migrate outward during an inflammatory reaction [18].

The hydrodynamic theory, which is one of the most widely accepted theories of tooth pain mechanism, states that external stimuli such as mechanical and thermal stimuli can cause an inward flow of the dentinal fluid toward the pulp or outward flow of the dentinal fluid away from the pulp. This change in the dentinal fluid flow activates mechanoreceptors, thereby causing pain [19].

Su *et al*. used the fluid–structure interaction (FSI) method to investigate the flow of dentinal fluid under different loading rates and found that a lower loading rate of external forces caused a reduced fluid flow velocity in the pulp, thereby resulting in pain avoidance [20].

The dentinal tubule diameter differs significantly from the teeth of younger individuals, in comparison to the teeth of older individuals. Open tubule lumens are present in young dentin, whereas the tubule lumen is occluded with minerals in aged dentin. Hence, there are reduced fluid movements in aged dentin. The reduction of tubular lumen will not affect the tubular density. A higher calcium concentration in the dentin of aged teeth leads to higher hardness and higher elastic modulus, but there are no age-related differences regarding tubular density (the amount of dentinal tubules/per square millimeter). Mineral deposition takes place in the dentinal tubules along with the formation of secondary dentin in the interface dentin/pulp [21].

Intratubular dentin

The dentin present between the tubules is called intertubular dentin and is composed of a less-calcified matrix with some apatite crystals embedded within a collagen matrix[22]. Hydroxyapatite crystals are present along the fibers, with their long axis oriented parallel to the collagen fibrils [8, 9].

Similar to the root dentin, the intertubular dentin also contains a fine mesh of mineralized collagen fibrils which are 50–100 nm thick. However, its microstructure is denser than the root dentin, with only a few disordered fibers. These fibers too are heavily loaded with minerals. Consequently, this field of activity has garnered the interest of researchers and there are conflicting reports of collagen fibril orientation in intertubular dentin. One school of thought led by von Ebner suggests that the collagen fibrils are arranged primarily orthogonal to the tubules. However, Orban and Kramer observed that fibrils are arranged obliquely, orthogonally, and peripherally even along the dentinal tubules. While isotropic, random fiber orientation is observed in crown dentin, it is well aligned or resembles a narwhal tusk in root dentin. These variations in reporting about the two dentinal forms, that is, root dentin and intertubular dentin, could be attributed to the confusion triggered by the presence of odontoblast branching laterally from the tubules [23].

Age-related changes

Changes due to physical aging
Increasing age causes the deposition of secondary dentin, which is not uniform and occurs after root completion. In fact, its presence is continuous though it forms at a much slower rate than the primary dentin. The tubules are almost continuous with primary dentin but contain fewer tubules than primary dentin. To protect the exposure of pulp in older teeth, they are deposited on the roof and floor of the pulp chamber [24, 25].

Changes due to pathological or physiological insults
The formation of sclerotic dentin takes place, in response to pathological or physiological insults. Intertubular calcification occurs, which results in a decrease in the intertubular dentin tubule's diameter. This reduction in tubule's diameter is attributed to different reasons such as fatty degeneration, deposition of calcium salts, and dissolution with subsequent deposition of intertubular matrix [26].

Changes due to occlusal trauma
Occlusal trauma triggers a myriad of tissue changes culminating in the exposure of dentinal tubules, with subsequent dentin sensitivity and/or pain [27].

Changes due to attrition and abrasion
Attrition and abrasion cause the collagen fibrils and apatite crystals to form an irregular mesh work in the dentinal tubules. This irregularity explains for the discrepancy in the refractive indices between intratubular organic and extratubular inorganic materials, resulting in translucency of the dentin [26].

Changes due to developmental anomalies
Developmental anomalies of dentin give rise to varied types of dental disorders like dentinogenesis imperfecta, dentin dysplasia, rickets, and familial hypophosphatemia. These developmental anomalies are majorly responsible for discoloration of the tooth bulbous crowns and pulp obliterations, tubular defects, and poorly mineralized globular dentin [28].

Changes due to chemical and thermal insults
Chemical factors result in the removal of the smear layer, which thus exposes the dentinal tubules and in turn leads to dentin sensitivity [29]. Just as a cold insult causes the tubular fluid volume to shrink slightly, thermal insult or heat causes the tubular fluid volume to expand [30].

Dentin bonding
Dentin bonding is a process by which the dentin and organic molecules of the dentin bonding agents (DBAs) and the monomer of the restorative resin react to form a biocomposite of dentin collagen and cured resin. Dentin conditioning involves the removal of the smear layer, thus facilitating the bonding for DBAs [31, 32].

The bond strength of DBAs from the first generation to the last generation varies from −1 Mpa to 25 Mpa.

The mechanism of bonding of DBA to the dentin differs from one generation to the other. The first generation relied on ionic bonding to hydroxyapatite or covalent bonding to collagen. The second generation was based on the ionic bond between calcium and chlorophosphate groups. The third to seventh generation was based on the mechanical interlocking of the etched dentin, followed by the hybrid layer formation. However, these generations of DBAs were technique sensitive. But the most recent eighth generation is composed of nanofillers that act as crosslinkers and enable a better penetration of resin monomers [33].

Dentin bonding is done either with an etch-and-rinse (ER) or a self-etch (SE) adhesive. These techniques provide a pathway for the adhesive resin to infiltrate into the collagenous matrix. In an ER adhesive system, the etchant (acid) dissolves the minerals to a depth of 5-10 µm, providing a route for resin infiltration and exposes the collagen suspended in water [34]. Whereas an SE adhesive system consists of an acidic resin monomer that concurrently etches and primes the substrate. These adhesives contain solvents like water, acetone, or ethanol to dissolve the monomer, maintain the collagen fibrils in their state, and allow the spaces around the collagen fibrils to be filled with monomer [35]. The action of acid demineralizes the dentin and creates a pathway for the resin to get infiltrated. This layer where the resin of the DBA micromechanically interlocks with the intertubular dentin and the surrounding collagen fibrils is called the hybrid layer (Fig 2) [36]. The success of restoration speaks volumes about the long-term stability, durability, and quality of the hybrid layer. There are certain characteristics, which are necessary for the formation of an effective hybrid layer, such as those given below:

- During decalcification, the dentinal peptides should not be denatured. If the acid used is too aggressive, it can expose the collagen underlying the hybrid layer, which will eventually leave a zone of weak dentin.
- The bonding agent should contain both the hydrophobic and hydrophilic groups.
- In the presence of oxygen and water, the catalyst should allow polymerization to take place [37].

A bond strength of 20-25 MPa is attained in the bonding composite resin to acid-etched enamel surface and dentin surface. However, as the surface contamination reduces 20% to 100% of the bond strength, moisture control is essential in dentin bonding [38]. Unlike enamel, dentin as a bonding substrate poses numerous challenges with regard to its mineral and water content. The 'Wet bonding' concept was introduced to overcome the complete drying of dentin which led to a poor bond strength. DBA evolved to certain generations to improve their bond strength [39].

During air-drying, the solvents evaporate, thereby increasing the concentration of non-volatile monomers and subsequently decreasing the vapor pressure of the remaining solvents. Thus, it is impossible to evaporate all the solvents clinically. Takai *et al*. observed that increased air-drying time of the dentin surface removed water and decreased the bond strength of a solvent-free one-step adhesive [40].

Fawzy *et al*. observed that the ability of the demineralized dentin collagen to resist air dehydration and to preserve the integrity of a collagen open network structure with increasing air-exposure time increased with the depth of dentin [41]. Fawzy *et al*. in yet another study observed that with increase in air-drying time, a decrease in the nanoscale adhesion force was observed. He postulated that this phenomenon could have taken place due to dehydration of the demineralized collagen fibrils' network surface [42].

Hass *et al*. reported that crosslinking primers minimized the time for degradation of the micro tensile bond strength (µTBS). However, this process did not alter the adhesive polymerization but instead reduced the collagenolytic activity of matrix metalloproteinases (MMPs). They also observed that glutaraldehyde reduced cell viability significantly [43]. The study on the marginal sealing of adhesive restorations by Maior *et al*. showed that the collagen fibrils were not necessary for adhesion, and that their removal positively influenced the marginal sealing of One Coat Bond and Prime&Bond NT [44].

Effects of dentinal changes on dentin bonding

The bond strength to dentin not only varies due to its material but also depends on the substrate factor such as its calcium concentration, moisture content, and its humidity. Sclerotic dentin is less receptive to the present adhesive system, especially in the case of abrasion or cervical erosion. The hybrid layer becomes reduced in size. The bond strength is determined by the available solid dentin. As the area occupied by the tubules in deep dentin is greater than in superficial dentin, reduced bond strength is displayed. Even in young dentin, the bond strength is lower due to the presence of wider tubules and lesser degree of mineralization [45]. The acid-etched surface of sclerotic dentin, which is shown to be naturally aged in scanning electron microscopy, did not etch the sclerotic dentin adequately and there was no retention for the adhesive resin. The sclerotic casts and mineral salts present in the intertubular dentin were not effectively demineralized by the acid etchant. This compromises the resin infiltration in aged dentin and its long-term durability[46]. Few studies have specified that dentin hardness increased with age. There was a higher degree of mineralization in the aged dentin, which increased the dentin hardness. Aged dentin is more resistant to acid etching because of its higher mineral content. Furthermore, the hybrid layer found in this etched aged dentin is narrower. This change is also seen in other hypermineralized areas like caries-affected occlusal dentin, noncarious cervical lesions, and artificially hypermineralized dentin.

The resin tags are tapered, which suggest that it is difficult to etch hypermineralized peritubular dentin for the standard 15 seconds. Whereas, when the etching time is doubled (30 seconds), a homogeneous hybrid layer is formed and the peritubular dentin becomes sufficiently demineralized. Therefore, it is postulated that increasing the etching time to 30 seconds provides adequate demineralization, exposes the intertubular collagen, and enables the formation of a homogeneous hybrid layer. This results in the bond strength of aged dentin to be similar to that of young dentin [47].

Conclusion

The goal of a bonded restoration is to form a close adaptation of the restorative material with the dental structure, which is able to restore the teeth. However, in reality this is difficult, as the bonding processes are different for both enamel and dentin. Dentin has more organic content, more humidity, and is more dynamic than enamel. The physical and mechanical properties of human dentin undergo changes with age. These changes influence the bonding processes of the various restorative materials employed to build the tooth back to form and function. A thorough understanding of the age-related changes at various stages are important for the development of successful strategies in treatment planning or in research for newer materials to be developed or tested for use in bonding to dentin.

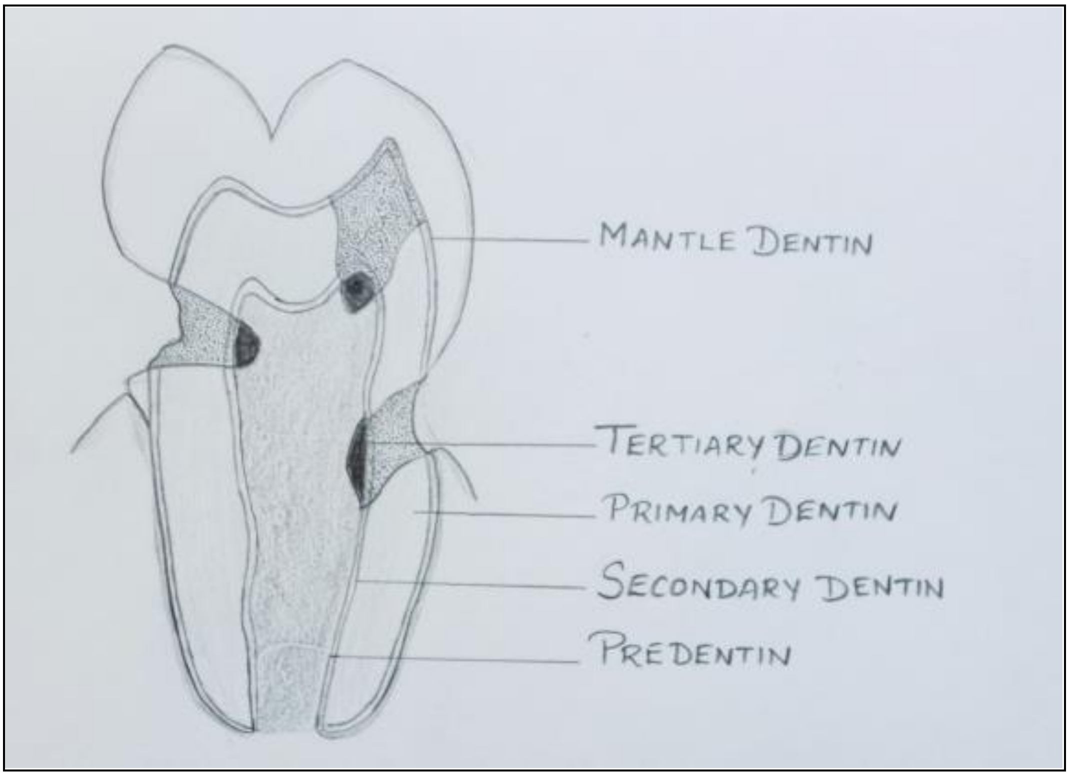

Fig 1: Types of Dentin

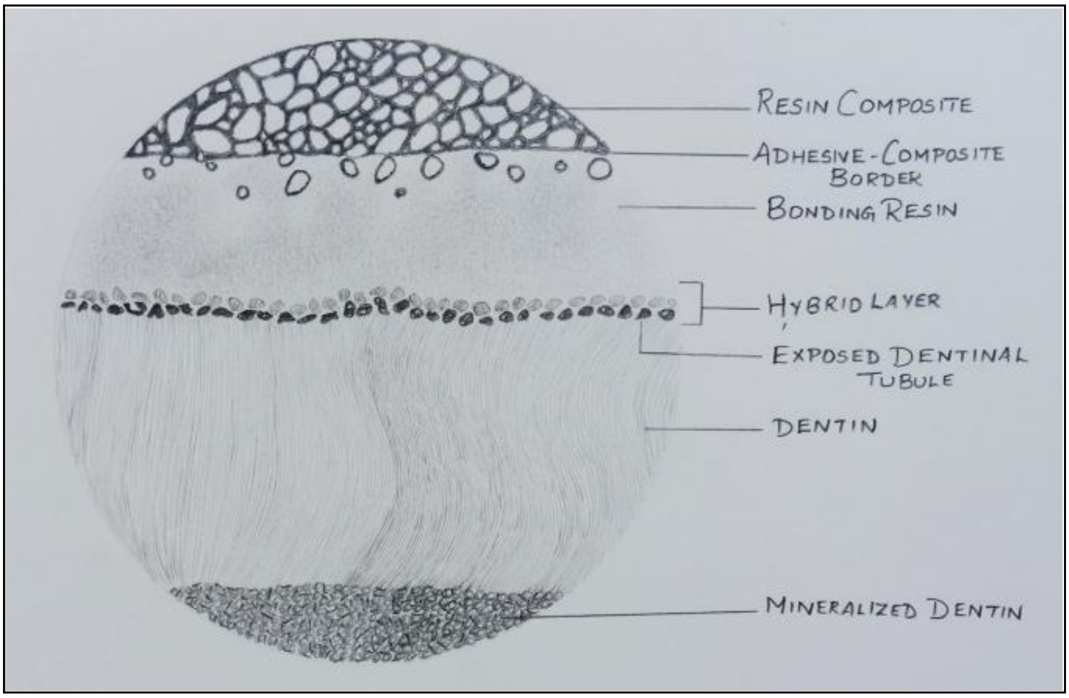

Fig 2: Hybrid Layer

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Conflict of Interest

Not available

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