Review Article

"It doesn't matter what lost what matter is what remains" R.D.T (Remaining Dentin Thickness): A review

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DOI:10.47750/pnr.2022.13. S01.120

Abstract

Thickness of residual dentin following cavity preparation or intra-radicular procedures is the factor as it affects the pulp vitality, permeability of tooth, and also fracture resistance of the root. Although, various methods were described to calculate the residual dentin thickness in vitro over the decades of research the brief description about different methods for calculating it is not considered, and also methods to measure RDT in vivo is never discussed. Thus, this review discusses various methods of calculating RDT in patients as well as in the laboratory.

Keywords: remaining dentine thickness (RDT), Role of RDT, Measurement of RDT.

INTRODUCTION

"Teeth can help us understand ecology, the study of how living things interact with one another and their physical environment."
Peter S. Ungar

Dentin surrounds the pulp in the crown as well as the root portion of the tooth. As dentinal tubules are present in the entire thickness of dentin, it may permeable to bacteria/chemical irritants which lead to pulpal irritation. Therefore, improved knowledge regarding dentin structure and properties is important in both restorative and endodontic procedures.[1]

Beyond the properties like resiliency, hardness, strength, fracture resistance, etc. thickness of dentin is very important for the success of conservative or endodontic treatment.[2] Remaining dentin thickness (RDT) is also known as residual dentin thickness. It is a key factor for establishing conservative as well as endodontic treatment and is first suggested by Stanley in 1984. [3,4] Although, various methods were described to calculate the residual dentin thickness in vitro over the decades of research the brief description about different methods for calculating it is not considered. Thus, this critical review re-exercised the different approaches for calculating remaining dentin thickness.[2]

Importance of thickness of dentin:

The thickness of dentin affects the pulp vitality and permeability of the tooth. As the remaining dentine thickness decreases, the number of odontoblasts also reduces. This causes the pulpal inflammation by allowing the bacteria and their by-

products to reach the pulp and periradicular area more easily.[5] According to Brännström (1976), 40,000-41,000 tubules/mm2 of 1.6-1.7 μm in diameter are present at 0.4-0.5 mm from pulpal surface in permanent teeth while in deciduous teeth, 26,390 dentinal tubules/ mm2 of 1.3 μm in diameter are present. So, to prevent tooth sensitivity, the remaining dentin provides buffering capacity and also insulation.[6] For example, in the case of stressed pulp, additional trauma leads to pulp degeneration. Therefore, estimation of residual dentin thickness protects the pulp from injury/ inflammation.[7]

Restorative dentistry: In restorative dentistry, the remaining dentine thickness is considered for protection of the dental pulp to various tooth preparation techniques and restorative materials as well. Sufficient RDT protects the pulp from vibration injuries and frictional heat which is generated by bur during tooth/cavity preparation. It also protects the pulp from cytotoxic injuries which may be due to acid etching or restorative materials, as RDT maintains the buffering action of dentin.[6]

According to Pameijer et al. (1991), RDT of ≥ 1 mm would be enough to protect the pulp tissue from the cytotoxic effects of certain restorative materials like zinc phosphate.

According to Stanley (1984), an RDT of 2 mm would protect the pulp from injury caused by restorative materials and treatment procedures.

According to Murray et al. (2003), RDT of ≥ 0.5 mm is necessary to avoid pulpal damage.

According to Fuks et al (2010), if RDT is <0.25mm then bacteria that are present in the cavity can cause an inflammatory reaction within the pulp.[8]

Different Pulpal responses related to RDT of the prepared cavity (according to Peter E. Murray):

These 3 responses attributed to the amount of cellular injury and buffering capacity of dentin

1. Most sensitive response:
   a) Odontoblast survival
   b) Extent of reactionary dentin secretion

2. Less sensitive response:
   a) Pulpal inflammation
   b) Cavity wall depth

3. Least sensitive response:
   Restorative factors

Table 1: Effect of RDT on odontoblast survival, formation of reactionary dentin and pulpal inflammation

RDT of prepared cavity	**Percentage of odontoblast survival**	**Reactionary dentin formation**	**Pulpal inflammation**
>1 mm (Shallow cavity)	100%	Slight	Minimal
0.5-1mm (Moderate cavity)	88.9%	Slight	Minimal
0.25-0.50 mm (Deep cavity)	82.5%	Significant	Increasing
<0.25 mm (Very deep cavity)	68.2%	Slight	Severe

Table 2: Percentage of different restorative materials for the survival of odontoblast when RDT < 0.5 mm (According to Peter E. Murray):

Restorative material	**Percentage**
Calcium hydroxide	100%
Polycarboxylate	81.1%
Zinc oxide	78.4%
Composite resin	74.2%
Resin modified glass ionomer cement	43.1%

This shows that cytotoxic material must be avoided in very deep cavity preparations.[9]

Endodontics: a most important and critical step in the endodontic treatment procedure is the instrumentation of the root canal because, without proper cleaning and shaping, root canal treatment cannot succeed. During the shaping of the root canal wall, RDT plays a major role as it limits the root canal instrumentation so that the root canal wall would not get weakened. This shows that root strength is directly proportional to RDT. According to Katz et al in 2006, approximately 1mm of dentin should be present circumferentially in the entire length of the root after root canal instrumentation otherwise it may lead to strip perforation and vertical root fracture.[10] Therefore, thorough knowledge of anatomy and thickness of dentin in different regions of the root is essential.[11]

Hence, the following points must be kept in mind during the restorative or endodontic procedures:

1. To reduce the risk of fracture while preparing post space, ≥1mm of RDT must be present circumferentially in the root.

2. Cytotoxicity of restorative material is inversely proportional to RDT
3. Bond strength of resin based adhesive system is directly proportional to RDT

4. Hydraulic conductance of radicular dentin is inversely proportional to the distance from the pulp (i.e, as the distance from pulp, increases hydraulic conductance of root dentin decreases)

5. Heat induced pulpal injury (via curing light or burs) is inversely proportional to RDT [5]

Table 3: Classification of the cavity according to remaining dentin thickness [12]

Restorative material	**Percentage**
Calcium hydroxide	100%
Polycarboxylate	81.1%
Zinc oxide	78.4%
Composite resin	74.2%
Resin modified glass ionomer cement	43.1%

Approximately 2mm of RDT or otherwise equivalent material thickness should use to protect the pulp. However, 1-1.5 mm of dentin thickness is also acceptable for insulation. But this dentin thickness is not possible always practically. Therefore, as tooth preparation extends near the pulp chamber, a thick liner or base must be advised.[13]

Recent advances in liners and bases:

Recently various advances are done in base material like TheraCal LC, TheraBase, biodentine, Endosequence BC liner, e-MTA, nano WMTA, etc. TheraCal LC, TheraBase are introduced by BISCO. TheraBase is a self-adhesive cement used for both indirect and direct composite restorations. TheraCal LC is a light cure resin modified calcium silicate liner.[14] By forming a calcific barrier TheraCal LC protects pulp-dentin complex. Biodentine is also a calcium silicate-based material that was introduced by Septodont in 2009. It shows a positive effect on tertiary dentinogenesis. Fast setting that is, within 45 minutes is the unique property of this material. Endosequence BC liner is a bioceramic cement and is used as a liner or base over the access opening [15] e-MTA is a recently introduced calcium silicate-based material that contains ultrafine grained particles. Unlike MTA, e-MTA sets quickly and has regenerative potential along with antimicrobial properties. Recently nano WMTA was introduced by NanoTech Egypt. The manufacturers of nano WMTA claimed that its particle size is reduced so that it provides a faster hydration process.[16]

Methods for calculation of remaining dentin thickness:

Clinically, it is difficult for the dentist to evaluate the RDT which is left over the pulp after the cavity preparation or shaping and cleaning of the root canal or post space preparation. So,during treatment, the dentist can make only a rough estimation of the amount of dentin left.[17] However, various methods were described in the literature which may help in determining remaining dentin thickness which is as follows:

1. **Radiographic method**: Intraoral periapical radiograph is not the reliable method for measuring RDT because of distortion of the image either in the form of elongation or foreshortening of the image. Although the paralleling technique may reduce the chances of distortion but morphologic variations in the patient's mouth might create problems while performing paralleling technique.

2. **Radiographic grid method**: To overcome the short comings of the radiographic method, Everett and Fixot in 1963 introduce the radiographic grid method by incorporating metallic grids in the radiograph. However, as they were of metal so they pose a problem while placing within the patient's mouth. Secondly, they were highly radiopaque so they mask the anatomic structure.

To overcome this problem, Larheim and Eggan (1979) introduce a non-metallic radiolucent grid. But their incorporation into radiograph was a very cumbersome procedure. Therefore, in 2008, Krithika et.al, introduces an easier method for their incorporation into radiographs.

Procedure- dye (radiosensitive iodine-based, water soluble) loaded canvas meshwork made up of knitting material firstly stuck into the radiographic film and then placed in a plastic sleeve. Then this radiographic film which is placed in a plastic sleeve would be used for taking the radiograph. As dye forms a layer over canvas which provides good contrast of radiolucent lines of canvas which will be visible in the radiograph. These radiolucent lines are easy to count and are visible over the teeth. Thus, helps in measuring RDT.

Nowadays, IOPA grids (figure 1) are also available which are made up of copper wire. These IOPA grids when superimposed with film, they show anatomic structures with grid lines. These grid lines are evenly distributed which is 1mm part length-wise and width-wise. These fine lines are accentuated by heavier lines at every fifth millimeter. Therefore, IOPA grids consist of 2 types of line fine (act as scale) and thick (makes reading easier).[18]

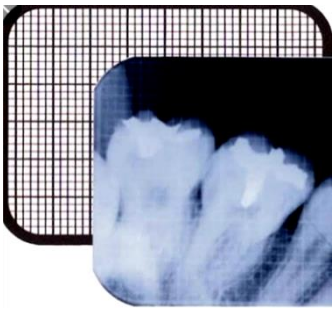

Figure 1: IOPA grids

Advantages-

a) As grids and radiograph exposed at the same time interval, so helpful inaccurate measurement.

b) Suppose if distortion occurs, even then grid line can be useful to measure the distance between grid lines because they will still be 1mm to each other.
c) Simple and effective method.[19]

3. **Digital radiographic technique superimposed with radiolucent grid lines**.[19]

4. **EndoEst 3D** (figure 2): It measures the electric resistance of the dentin which thereby determines the thickness of the remaining dentin. It is primarily used for measuring RDT in cases of crown preparation.

Working mechanism- it consists of 2 electrodes, a reference electrode (lip clip), and a measuring electrode (placed on the prepared tooth). The flow of current between these electrodes depends on the permeability of dentin. This means that the

Figure II: EndoEst 3D

same electronic resistance may be observed in both thick dentin with wide-open tubules and thin dentin with narrow dentinal tubules. This electric resistance is measured to evaluate the thickness of the dentin. This device is a multifunctional device as it consists of a dentin meter (measure dentin thickness), apex locator (locate apical constriction of the root), and pulp tester (assess the condition of the dental pulp).[20]

5. **Ultrasonic micrometer**: Baum et.al (1963) was the first to employ the noninvasive ultrasonic diagnostic technique to the teeth.[21] Its principle of generating ultrasonic pulse and echo from ultrasonic thickness gauge is similar to sonar/radar.[22]

Working mechanism- it consists of a transducer, pulse receiver, and oscilloscope.[20] When the transducer is placed into the prepared cavity or tooth, it tends to vibrate piezoelectric crystals which convert electric energy to sound energy. When stimulation is provided to the transducer, these crystals produce ultrasonic waves which travel through the tooth until they reach to interface with different acoustic impedance. In this interface, the ultrasonic pulse is reflected back to piezoelectric crystals. Due to these crystals get excited and form electric signals. These signals then reach the receiver and the RDT is determined by calculating the time between the pulses:

Distance = ½ velocity X Time

Drawbacks:

a) If non-parallel surfaces are present like pulp horns, then the percentage of the signal gets directed away from the transducer and receiver as well. So, if a significant wave portion gets lost, the return pulse also gets weak to generate an echo.
b) It requires frequent adjustment of ultrasonic gauge angle so that a sufficient amount of magnitude is obtained for measurement in the thickest portion. However, this is quite difficult in prepared curved surfaces of cavity or tooth preparation.[22]

6. **Prepometer** (figure 3): this instrument is invented by Hager in 2007. It is a battery powered instrument that helps to limit the preparation depth using colored light emitting diodes, basically designed for determining the RDT during crown preparation by measuring its electric resistance.

Parts- it consists of a handpiece, measuring electrode which would be placed on the prepared tooth, reference electrode on lip clip, an auxiliary electrode for calibration (allows the prepometer to save resistance values which are measured between pulp and reference electrode), battery, and 10 LEDs.

Principle- smaller the remaining dentin thickness, the greater is the passage of electric current. This shows that the flow of current is affected by the permeability of dentin.

Working mechanism- the electric resistance of the tooth is measured when the alternating current flows between the measuring and reference electrodes. This reading is then displayed on the unit. Low electric resistance values are obtained when there is high permeability of dentin while high resistance values are obtained when dense dentin is present. As the electric current decreases, the LED light color changes from green to red. These values can be visualized by different color codes. The time required for each measurement is only 10 seconds. Different color changes indicate:

a) Green LED- tooth cutting is not risky

b) Yellow LED- further tooth cutting is still possible

c) Orange LED- safe zone for cutting is now limited

d) Red LED- RDT is now > 1.4mm, so there is a danger of pulp exposure.

According to Netsch (1995) and Bruchmann (1998), prepometer measures the electric resistance of dentin which indicates wound size made in dentin during tooth preparation rather than RDT. Also, its working is questionable in older patients due to the presence of sclerotic dentin.[23]

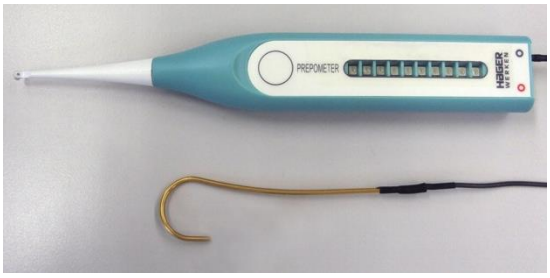

Figure 3: Prepometer

1. **Optical coherence tomography (OCT)**: In dentistry, OCT was first used in California in 1998.[24] It is a noninvasive laser method. First described by Fujita et.al, in 2014 to measure RDT. Although there are different types of OCT, recently introduced SS-OCT which uses swept laser with a tunable wavelength of the diode laser is now Days used for measuring RDT. It uses the wavelength of 1050 nm, the axial resolution of 5.3µm, and an axial scan rate of 100,000scans/second.

Working principle (Figure 4)- It consists of software and 5 modules, i.e, light source, imaging apparatus, measurement head, the module of data processing, and computer control system (CCD). The partially coherent light source, determine the axial reduction and penetration depth of the light beam. The imaging apparatus measures the reflected as well as backscattered light with high resolution and sensitivity. The measuring head acquires measurement data from the measuring apparatus. CCD controls the entire OCT scanner and allows communication between apparatus and image processing block and also displays the measurement result. The measurement of intensity and time delay of "echo" from reflected/backscattered light makes OCT imaging possible.

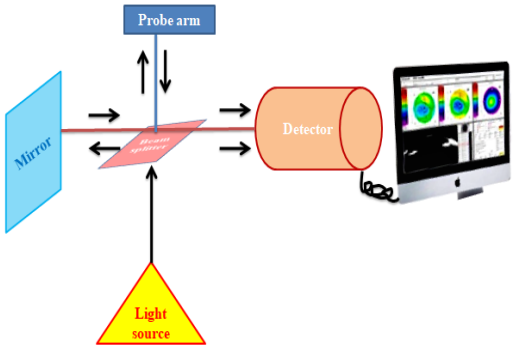

Figure 4: Optical Coherence Tomography

Advantages- OCT imaging and ultrasonography differ from each other in data measuring technique i.e, light speed (used in OCT) is much greater than sound speed (used in ultrasonography). That is the reason for the high-resolution image obtained from OCT (10μm) compared to ultrasonography (150μm). Another difference is depth penetration, i.e, light waves may reach up to the depth of 2mm and sound waves reach only up to 10 cm. [23]

1. **Cone Beam Computed Tomography** (figure 5): It generates 3-dimensional images with less radiation dose as compared to conventional computed tomography.

Figure 5: CBCT Unit

Working mechanism- in CBCT cone-shaped x-ray beam centered on the detector which rotates around the object, thus producing series of 2-dimensional images. Then with the help of the original cone-beam algorithm which was invented by Feldkamp (1984), this series of 2D images were converted into 3D images.[25]

2. **Micro-computed tomography & virtual simulation technique**: It is also a non-invasive & nondestructive method that provides a 3-dimensional image of the tooth. 3D micro-CT data generate 2D simulate radiograph with the help of direct ray casting technique within the software (without taking real radiograph), helps to measure RDT.

According to Gao et.al, (2009), this virtual simulation generates a virtual digital radiograph that assesses the RDT of the root portion and also facilitates the realistic simulation of variations in RDT which are commonly seen in the root. However, CBCT is an accurate technique for the determination of RDT, but it is not cost effective and its radiation dose is also quite higher for patient.[26]

Various in-vitro methods for calculating RDT are as follows:

1. **Sectioning and microscope analysis** (figure 6): In this method, extracted teeth were sectioned into slices of particular thickness with the help of a diamond saw at low speed and then examined under a stereomicroscope for measuring RDT.[27]

Figure 6: stereomicroscopic image of sectioned tooth slice

2. **Radiographic and Photographic imaging**

3. **Sectioning and Muffle block system** (figure 7): First performed by Bramante in 1987 and he referred to it as "Endodontic cube". It is also known as the Bramante muffle system. It consists of 5 brass sections held by eternal fixation, forming a roofless cube. In the internal surface of this cube, indexing is present which acts as a guide.[28] Later it is modified as a Teflon muffle system in which instead of brass wire metallic rods with metal springs are used to support muffle mold. It is also easy to open and for reassembling.[29]

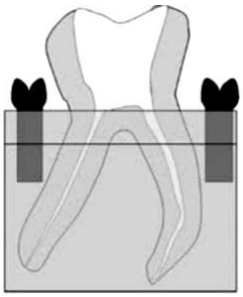

Figure 7: Schematic diagram of muffle system

Working mechanism- the inner surface of the muffle mold coated with Vaseline then acrylic resin is poured into which root is embedded in the indexing area. When acrylic resin sets completely, it will be removed from the muffle system sectioned vertically with the diamond disc. Then sectioned parts can be examined under the scanner.

Advantages-

a) Unlike the radiographic/ microscopic method in which only RDT of root after instrumentation can be measured, this technique enables the researcher to compare the root RDT of the root canal before and after the instrumentation.
b) Helps in measuring the RDT at any level with minimum removal of tooth structure.[29]
c) Simple and economic.

Disadvantages-

a) Destructive method.

b) Among the slices of muffle, space gets created due to which there is loss of tooth structure and also working length.[28]

4. Ultrasonography

5. Prepometer

6. **Optical coherence tomography** (figure 8): for laboratory determination of RDT, the tooth is sectioned into blocks with the help of low speed saw. Then block is mounted on a glass slide and stabilized by a custom made jig such that the block will be parallel to the probe. So, when the light passes from the source through a beam splitter, 50% of the light gets directed towards the subject while remaining towards the reference mirror. Backscattered light (from the subject) and reflected light (from the mirror) move towards the detector where it produces "waveform" by interfering with each other.

It was observed that if the dentin thickness is greater the length change rate of the OCT image is also greater. This is due to the directionality of dentinal tubules and their heterogeneous composition.[4]

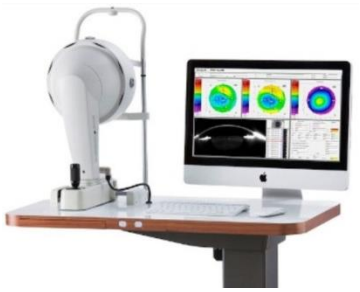

Figure 8: optical coherence tomography unit

Conclusion

The common delineator during conservative treatment procedure or endodontic treatment is tissue preservation, by preventing the disease from occurring and intercepting its progress, and also removing and replacing with as little tissue loss as possible. for this, minimally invasive dentistry (MID) is a concept that can embrace all aspects of the profession. this MID has a direct relation with the preservation of remaining dentin thickness. Further development is needed for the development of equipment that measures RDT chairside.

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