INTERNATIONAL JOURNAL OF DENTAL MATERIALS VOLUME 2 NUMBER 1 JANUARY-FEBRUARY 2020

ISSN: 2582 - 2209 (ONLINE)

INTERNATIONAL JOURNAL OF DENTAL MATERIALS

VOL. 2 NO. 1 JANUARY - FEBRUARY2020

International Journal of Dental Materials

Volume 2 Number 1 January-February 2020

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Focus and Scope

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Publication Information: International Journal of Dental Materials 2020, volume 2, issue 1 is scheduled for publication. Further details or information is available on this journal's website (http://ijdm.co.in/index.php/dental-materials/).

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Original Article *International Journal of Dental Materials 2020; 2(1)* **e-ISSN:2582-2209**

Evaluation of the accuracy of working length determination and automatic apical reverse function accuracy of endodontic rotary motor integrated apex locator: an *in-vitro* study

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INFORMATION

Article History

Received *2nd January 2020*
Accepted *31st January 2020*
Available online
9th March 2020

KEYWORDS

Automatic apical reverse
Electronic apex locator
Endodontic motor
Working Length

ABSTRACT

Background: The outcome of a Root canal therapy depends upon complete cleaning of the root canal system without damaging periapical integrity. Accurate determination of working length determination is essential. The development of Endodontic motor integrated apex locators (EALs) for locating canal terminus has been significant innovation in the field of Endodontics.
Aim: To evaluate the accuracy of Endomotor integrated electronic apex locator in determining the working length before and after cleaning and shaping with Automatic Apical Reverse action set at the "0.5mm" mark.
Materials and methods: Forty extracted premolars were decoronated, patency was verified. The actual length of tooth measured and teeth were embedded in alginate and file was advanced. Readings at the apex and 0.5mm short of the apex was recorded using Dentaport ZX (DZ group) and EConnect S (ES group) apex locator. Cleaning and shaping were done with rotary files with Automatic Apical Reverse action set at 0.5mm short of apex and reading recorded as Automatic Apical Reverse Length (AARL), and actual tooth length is measured. The data obtained were statistically analyzed.
Results: Within the limitations of the study, the EALs readings of the DZ group & ES group provided an acceptable determination of working length within range ± 0.5mm, and AAR function set at 0.5mm mark of Endomotor integrated apex locator (E Connect S) provided an adequate apical limit.
Conclusion: Under the *in vitro* conditions of this study, both Electronic Apex Locators showed an acceptable determination of working length within range ± 0.5mm from the actual length. The AAR function set at the 0.5mm mark of Econnect S provided an adequate apical limit.

1. Introduction

Root canal therapy (RCT) is the most common treatment for the pulpally diseased teeth; determination of appropriate working length is one of the vital factors for the success of root canal therapy [1]. According to the Glossary of endodontic terms, "the working length (WL) is defined as the distance from a coronal reference point to the point at which canal preparation and obturation

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How to cite this article: Nanda Kishore K, Madhu Varma K, Sajjan GS, Kalyan Satish R, Raheem Md, Viswanadhan A. Evaluation of the accuracy of working length determination and automatic apical reverse function accuracy of endodontic rotary motor integrated apex locator: an *in-vitro* study. Int J Dent Mater 2020;2(1): 1 - 4.

should terminate". The traditional method of determining the WL was by taking the intraoral periapical radiographs. With the advent of Electronic apex locators (EALs) in the endodontics has helped to make determining the WL more precise, accurate, and predictable [2,3]. Different generations of EALs have been introduced in the market to locate the root apex for measuring the WL. Endodontic motor integrated EAls have been developed, making the root canal therapy faster and simpler [4,5]. These hybrid devices not only have the torque and speed control but also aim to monitor and maintain the apical limit during mechanical shaping of root canals [5]. The Automatic Apical Reverse (AAR) function stops and reverses the rotation when the specified point is reached by the file tip. This function allows controlling the apical extent of canal instrumentation. The AAR function can be set at different levels indicating file closer or away from the apical constriction. The AAR function has been set at the "0.5 mm" mark as it corresponds to the location of apical constriction (AC), and the APEX mark corresponds to the tip of the file at apical foramen (AF). The DentaPort ZX (Morita, Tokyo, Japan), is a frequency-dependent device, determines the position of the WL by simultaneous measurement of impedance values in the same canal using two different frequencies (8 and 0.4 kHz) [6]. The EConnect S (Eighteeth, China) is a multi-frequency based EAL with high precision and accuracy, which can function as low-speed handpiece and apex locator or combination of both. In the present study, Dentaport ZX (DZ group) was used to compare the accuracy of the apex locator alone with E Connect S (ES group). This in-vitro study aimed to evaluate the accuracy of Endomotor integrated electronic apex locator in determining the working length before and after cleaning and shaping with Automatic Apical Reverse action set at “0.5mm” mark.

2. Materials and methods

Forty extracted human premolars were taken, which are free of caries, single-rooted, and with a single canal were selected. Teeth with developmental disturbances, with caries, teeth which are multirooted, calcified, with open apices and presence of extra canal, were excluded from this study. The teeth were decoronated with a diamond disc to obtain a standard length of 15mm and to obtain a plain surface. A size 15K file (Dentsply Maillefer, Ballaigues, Switzerland) was used to confirm the patency and presence of a single canal. The root canals were pre flared using SX rotary instruments (Dentsply Sirona) with 2.5% sodium hypochlorite (NaOCl) as an irrigating solution. The AF standardization and visual measurement were performed under the Dental Operating Microscope until the tip of the 15 k file visible at the most coronal border of AF opening. Then the rubber stop was adjusted to the reference point. The distance between the rubber stop and file tip was measured with a digital caliper (DC) to 0.02 mm precision and recorded as actual length (AL). The teeth were embedded in a freshly made alginate.

2.1 Apex locator function

To evaluate the apex locator function of the devices, the 15 K file was inserted into the root canal, and the device was connected to the lip clip placed in alginate and the file holder to the 15K file. The file was advanced into the root canal until the "APEX" mark and distance between the reference point and file tip was recorded as (EL APEX). Then file withdrawn until the"0.5" mm mark of the device to obtain the electronic working length (EL 0.5). The measurements were recorded if the mark displayed remained stable for at least 5 seconds. The electronic measurements of all 40 teeth were obtained with both the apex locators (i.e., Dentaport ZX and E Connect S).

2.2 AAR function

The AAR function of the Econnect S was adjusted to the “0.5” mm mark. The chemomechanical preparation was done with Protaper Gold (Dentsply Sirona) rotary instruments (up to F2) were used until the apical limit was reached, and the AAR was activated. Irrigation was done with 2.5% NaOCl following each instrument. The last file F2 was manually inserted into the extent of root canal preparation, and the rubber stop was adjusted to the reference point. The distance between the rubber stop and file tip was measured using a digital calliper and recorded as AAR length, which is also done with the Dentaport ZX apex locator. The teeth were removed from the alginate and washed, and a 25.02 stainless steel file was inserted into the canal up to AF to measure the actual length after preparation (AL2). All the electronic measurements were performed by a single operator who is unaware of visual measurements.

2.3 Statistical analysis

The data obtained were tabulated and statistically analyzed, from the measurements obtained by the EAL and AAR function, the AL and AL2 were subtracted.

The differences in the electronic readings were assigned as negative and positive, respectively. The Kolmogorov Smirnov test confirmed the normal distribution. The Analysis of variance test used to compare mean root length among measuring methods. The post hoc Tukey test was used to compare the percentage of distribution of the electronic measurements between devices (significance set at 0.05 level).

3. Results

The mean AL was 14.54 mm, and the mean length after preparation (AL2) was 14.43 mm; these results were not statistically different (p = 0.12). Table 1 presents the descriptive for the electronic measurements according to different functions. There was no significant difference among the two tested devices (p = 0.926). Tables 2 and 3 presents the EAL and AAR functions, respectively, in terms of the distributions and percentages of the difference between the electronic readings and the visual measurements.

4. Discussion

In the present study, the alginate medium was used to simulate the periodontium as it remains around the root, and its colloidal consistency presents a suitable electroconductive medium [7]. The teeth were Decoronated to create a flat, stable reference point to provide consistent measurements. The coronal pre flaring was done as it increases the accuracy of the EALs [8]. The tolerance range of ±0.5 mm for the EAL is considered acceptable [9]. Even the range of ±0.5 mm might overestimate the precision of EAL, most of the endodontic rulers can measure to an accuracy of 0.5mm. The EAL measurements for APEX and 0.5mm mark showed 100% within limits for both the Electronic Apex locators. The EALs were compared with Actual length as it is the constant landmark for evaluation, as it is expected that the morphology of AC might be altered during the shaping procedures [10]. The EAL readings beyond ±1mm are considered unacceptable as they lead to overestimation or underestimation of the root canals [1,9].

Table 1. Distance (mm) from the electronic measurements.

	EL APEX (n=40)		EL 0.5 (n=40)		AARL 0.5 (n=40)	
	Mean	S.D	Mean	S.D	Mean	S.D
DZ group	14.38	0.27	14.38	0.30	14.21	0.20
ES group	14.36	0.24	14.20	0.24	14.26	0.26

Table 2: Distribution and percentage of the difference between the Electronic lengths (ELs) and the actual length (AL) obtained at the APEX and 0.5mm mark of the tested devices for Apex locator function.

	APEX				0.5mm			
	ES group		DZ group		ES group		DZ group	
EL-AL	n	%	n	%	n	%	n	%
< -1.51	0	0	0	0	0	0	0	0
-1.5 to 1.01	0	0	0	5	0	0	0	0
-1 to -0.51	2	5	2	95	9	22.5	5	12.5
-0.5 to 0.00	38	95	38	0	31	77.5	35	87.5
-0.01 to -0.5	0	0	0	0	0	0	0	0
0.51 to 1	0	0	0	0	0	0	0	0
>1.01	0	0	0	0	0	0	0	0

Table 3: Distribution and difference between the Automatic Apical Reverse (AAR) length (AARL) and Actual length after preparation (AL2) obtained with AAR function set at 0.5mm mark of Tested devices.

	DZ group		ES group	
AARL-AL2	n	%	n	%
-1.5 TO -1.01	0	0	0	0
-1 TO -0.51	2	5	4	10
-0.5 TO 0.00	37	92.5	34	85
0.01 TO 0.5	1	2.5	2	5

For the EAL function, no overextensions were seen with both the tested devices. In the present study, a slight reduction in length after preparation (AL2) was observed, most probably due to the use of straight canals, and the actual length was obtained after cervical preflaring. The AL2 was measured to prevent bias from the alterations after the preparation of the root canals. In the present study entire preparation of the canals was controlled by AAR function set at 0.5mm mark, allowing reversing back after reaching the apical limit. In the literature, after shaping procedure, the apical limit is considered adequate with distance ranging from 0-1mm short of AF. In this study, the AAR function set at 0.5mm mark provided an acceptable apical limit. The acceptable apical limit seen with apex locator alone was 95% with the ES group and 97.5% with DZ group. Over instrumentation noticed with Econnect S apex locator in 5% of cases and 2.5% with Dentaport ZX apex locator. This might be due to the manual dexterity of the operator while placing the instrument (F2) manually into the canal after preparation. No incidence of under instrumentation was seen.

5. Conclusion

Under the in vitro conditions of this study, both Electronic Apex Locators (i.e., Dentaport ZX and Econnect S) showed an acceptable determination of working length within range ±0.5mm from the apex. The AAR function set at the 0.5mm mark of Endodontic rotary motor integrated apex locator (E Connect S) provided an adequate apical limit.

Conflicts of interest: Authors declared no conflicts of interest.

Financial support: None

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Review Article International Journal of Dental Materials 2020; 2(1) e-ISSN:2582-2209

Evolution of image receptors in dental radiology

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INFORMATION

Article History

Received *21st December 2019*

Received revised *11th January 2020*

Accepted *20th January 2020*

Available online *9th March 2020*

KEYWORDS

Image receptors,
Conventional image receptors,
Digital image receptors

ABSTRACT

The quality of a radiograph depicted by geometric and visual characteristics, in turn, also depends on the quality of image receptors. Image receptors in dentistry have seen an enormous evolution trend from conventional x-ray films to the current generation of digital image receptors. The development of cost-effective image receptors is established in various types of imaging procedures. The present article provides an insight into the evolution of various image receptors used in dental radiology.

1. Introduction

Image refers to a picture or reflection of an object. It is derived from the Latin word, imitate. An image is a reproduction or representation of the physical form of a person, or thing [1]. Receptor means anything that responds to a stimulus.

IMAGE RECEPTOR can be defined as a medium that changes the X-ray beam into a visible image. The absorption and scattering of photons out of the primary beam reduces a beam of x-rays photons that pass through the object. The x-ray film or image receptors help to record the information about the object through which x-rays penetrate and which help to form the image [2].

Dental image receptors used today are films, screen-film combinations, the electronic sensors that are used in digital imaging, and cone-beam computed tomography [3]. Image receptors can be Conventional receptors or digital receptors. This article provides a comprehensive overview of image receptors that are used and the current evolution of the same.

2. History of image receptors

2.1 History of conventional image receptors

From the time when X-rays were discovery by Wilhelm Conrad Roentgen in 1895, the film became the primary vehicle for capturing, displaying and storing radiographic images. Earlier in the 1900s, glass plates wrapped in the black paper were used as image receptors. With the improvement of the power supply, this photographic glass plates used as the image receptors were replaced by the films. Later the photographic cellulose film that had long been used for dental radiology replaced these plates [1].

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How to cite this article: Sudarsini PS, Rajesh N, Sudhakara Reddy R, Evolution of Image Receptors in Dental Radiology. Int J Dent Mater 2020;2(1): 5-10.

Dr Otto Walkhoff took the first original dental roentgenogram exposed on a portion of a glass imaging plate in January 1896. He took it in his mouth for an exposure time of 25 minutes [4]. Since then, dental imaging has shown tremendous progression along with its varied applications in fields of dentistry.

As early as 1896, Photographic film and paper had been tried for the recording of X-ray images. In 1896, William J. Morton used roll films manufactured by Eastman Kodak Company, and in 1900, Weston A. Price designed celluloid base dental film. In 1909, Kells reported using roll-type photographic film. However, despite their weight, bulk, fragility, cost, and patient discomfort in dental radiology, glass plates continued to be used.

In 1919, machine wrapped first dental film packet called Regular film (Kodak) was marketed. This film has emulsion on one side and was relatively slow; a molar exposure required 8-9 seconds. However, it produced sharp images. Later in 1924, the emulsion was placed on both sides of the film, that doubled the speed of the film (reduced exposure to 50%). This film was sold under the name Radiatized film (Kodak).

In 1924, the American Eastman Kodak Company turned out to be the modernizer of radiographic filming. In 1940, Ultra speed film was developed, and the speed of the film was doubled. In 1955, the speed rate of both these films was improved by a factor of 8. In the early 1980s, Ekta speed films were developed. These speed films further reduced exposure by 50% and are currently undergoing the slow but inevitable acceptance.

Later, a new dental x-ray film Dentus M4 was announced by Agfa. Eastman Kodak Co Kodak manufactured Ekta-speed plus films in 1994. Agfa Dentus M2 Comfort film was marketed in 1997. In 2001, F-speed films were introduced. Legacy of this progression of the ever faster film has been a concomitant lesser patient exposure. While changes in the film speed accompanied, the film base was also undergoing improvements. In the early 1920s, cellulose nitrate was used, which was highly flammable and when burned, it emitted large amounts of poisonous gases. Even though invented in 1906, a non-inflammable cellulose triacetate base was not marketed till 1924. As it has a disadvantage as a film base, that is expensive subject to mould, wrinkle, tendency to break. Until 1929, when a fire in Cleveland Hospital claimed more than 100 lives, cellulose nitrate continued to be the most popular base material. Later, the cellulose nitrate was replaced with cellulose acetate. In the early 1960s, the film base of polyester (poly ester film base) was introduced and has been the material of choice. This polyester film base can be made thinner and does not tend to warp as it is stronger than cellulose acetate.

The technology used for extra-oral imaging is as old as the discovery of X-rays. Yet today, dental radiologists are still finding new ways to improve diagnostic qualities of extra-oral radiography, at the same time reducing radiation exposure levels.

2.2 History of digital image receptors

In 1987, the dawn of the digital era in dental radiography came when the first digital radiography system called Radio Visio Graphy, was launched by the French company Trophy Radiologie in Europe [5]. Dr Francis Mouyen was the inventor of this system. He invented a method to employ fibre optics to confine a large image of x-ray onto a smaller size that could be detected by a Charge Coupled Device image sensor chip. The new technology was ready to expand. More than two decades after this, today's digital radiographic systems have developed a great superiority and have many benefits [6,7].

3. Classification

Image receptors can be divided into two types such as conventional receptors and digital receptors.

3.1. Classification of X-Ray Films

There are different types of X-ray films which are classified based on various criteria, as described in table 1.

The development of cost-effective Intraoral and extraoral digital technology, together with an increase in computerization, has made digital imaging a higher alternative in many aspects to conventional film imaging. Two technologies that create digital images include direct digital images and semi-direct digital images. Direct digital images are acquired by using a solid-state sensor. These solid-state sensors are based on charge-coupled device (CCD) and complementary metal-oxide-semiconductor (CMOS).Semi-direct digital images are obtained using a phosphor plate system [8].

3.1.1.Direct-action or non-screen film

These are sometimes referred to as wrapped or packet film. This film is sensitive primarily to X-ray photons.

3.1.2. Indirect-action or screen film

Indirect-action or screen film, so-called because it is used with a combination of intensifying screens in a cassette. This type of film is sensitive primarily to light photons, which are emitted by the adjacent intensifying screens.The advantage of intensifying screens and the indirect-action film is that they respond to shorter exposure to X-rays, allowing a lower dose of radiation to be given to the patient. However, this is at the cost of inferior image quality [9].

3.1.3 Intraoral films: (the x-ray film is inside the mouth)

3.1.3.1. Periapical Films

Periapical films are used to record the whole tooth, from the crown to beyond the root where it attaches into the jaw. Periapical x-rays detect any unusual changes in the root and surrounding bone structures. Film packs come in three sizes: size 0 for small children (22 X 35mm); size 1-which is relatively Narrow and used for views of the anterior teeth (24 X40mm); and size 2- the standard film size used for adults (31 X 41 mm) (Figure 1).

3.1.3.2. Bitewing film

Bitewing (interproximal) films (Figure 2) are used to record the coronal portions of the maxillary and mandibular teeth in a single image. They are useful for identifying interproximal caries and evaluating the height of alveolar bone. In small children, size 0 may be used, and the smaller size 1 is preferred in children. Size 2 film normally is used in adults. In some instances, long size 3 is used in adults, which measures 53x26cm.

3.1.3.3. Occlusal film (Sandwich radiography) [10]

Occlusal film measures about 57 x 76cm in dimension. It covers larger areas of the maxilla or mandible than may be seen in a Periapical film. The name comes from the fact that the film usually is held in position by having the patient bite lightly on it to support it between the occlusal surfaces of the teeth (Figure 3).

3.1.4 Extraoral films

These films are called screen films or indirect films as the radiographic film is placed between two intensifying screens within a cassette. Screen films are employed in extraoral radiography such as orthopantamograph, lateral cephalograph, skull views, TMJ views, and lateral oblique views of the mandible [7]. Extraoral films are usually available in the following sizes;

- 6X12 inches –orthopantomography
- 8X10 inches- all other skull radiographs: PNS, PA view, lateral cephalogram, etc
- 6X8 inches – TMJ views, lateral oblique
- 5X7 inches – This size is not often used. It may be used for transcranial films (used for TMJ views) or for lateral oblique jaw films.

3.1.5 Duplicating film

The duplicating Film is a type of film that is used to make an identical copy of an intraoral or extraoral radiograph. The film that is to be duplicated is placed against the emulsion side of the duplicating film, and both the films are held in position by a glass-topped cassette or photographic printing frame [2]. When the films are exposed to light, light passes through the clear areas of the original radiograph and exposes the duplicating film. The duplicating film is then processed in conventional film processing solutions. As on the original radiograph, areas exposed to light come out clearly. Duplication frequently results in obtained images with less resolution and more contrast than the original radiograph. The best images are obtained when the ultraviolet light source is used. Unlike intraoral radiograph, it is used only in a darkroom setting and not exposed to x-ray. It does not have an orientation dot.

3.1.6 Self Processing film

The self-processing film is an alternative to manual processing. The film is available along with the processing solutions. The x-ray film is presented in a single sachet containing developer and fixer (Figure 4).

3.1.7 Speed of the films

Film speed refers to the amount of the radiation that is required to produce an image of a standard density.

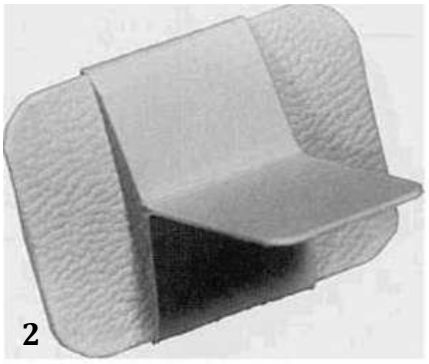
3.1.7.1 Slow speed films

The emulsion is present on one side only in the film with the small size of crystals. More exposure time is needed but better detail definition can be seen in A, B, and C speed films.

3.1.7.2. Fast speed films

The emulsion is present on both sides of the film. The

1



2

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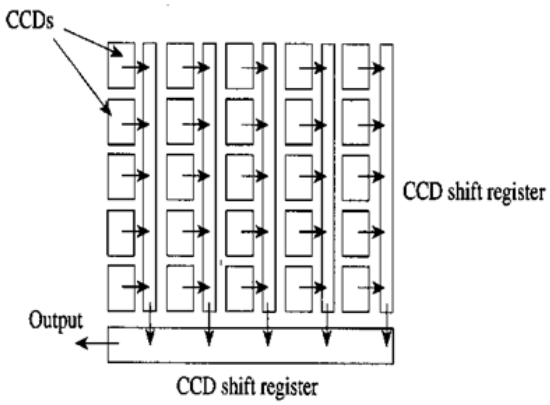
4



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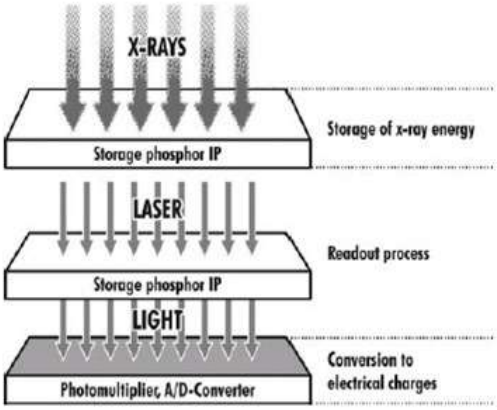

6

Figures 1. Size 2 periapical film, 2. Bitewing film, 3. Occlusal radiograph, 4. Self processsing film, 5. Bucket Brigade Pattern, and 6: PSP image processing

faster film has large crystals and the increased amount of silver bromide in the emulsion hence, they require less exposure radiation as seen in D-ultra speed, E-ekta speed, and F-ultra ekta speed film.

3.1.7.3. Hyperspeed G films

These are 800- speed films that can halve the exposure without blurring the image.

4. Digital image receptors

Digital imaging is similar to film-based imaging in the interaction of x-rays with a receptor, processing of a latent image, and in subsequent viewing of the image. In digital imaging, the image receptors are highly sensitive sensors and require considerably less radiation exposure than film. The data acquired by the receptor is analogue in the form of a continuous grayscale, and it must be converted to digital data that is to be useful.

The ADC or analogue-to-digital converter transforms analogue information into numerical information based on the binary number system. Computers operate this binary number system in which two digits (0 and 1) are used to represent information or data [11]. Digital radiography receptors include "direct" and "indirect" receptors. Direct receptors communicate with the computer with the help of electronic cable or, more recently, wirelessly. Indirect receptors require a scanning step.

4.1 Charged Coupled Device (CCD)

The CCD was introduced to dentistry in 1987. It was the first digital image receptor to be adapted for intraoral imaging [12]. CCDs are electronic devices, which convert light into electronic charge in a silicon chip (integrated circuit). This charge is digitized and stored on a computer as an image.

A CCD contains a sensor that is placed in the patient's mouth. A cable leads from the sensor to an interface, which is connected to a computer in the operatory. After exposure, x-ray energy is transformed into a proportional number of electrons, which are deposited in the electron wells, then transferred sequentially to a read-out amplifier. This analogue signal is converted to a digital signal, and then x-ray image is visible almost immediately on the computer monitor. The structure of CCD is a serial arrangement called "Bucket Brigade Pattern" (Figure 5). Sensors are available in different sizes such as size 0, 1, and 2 to simulate the various film sizes used clinically.

4.2Complementary metal-oxide-semiconductor

Complementary metal-oxide semi-conductors are silicon-based semiconductors; these are fundamentally different from CCDs in the way that pixels are read. Electron hole pairs generated in pixels are proportional to radiation dose. Each pixel is isolated from neighbouring pixels and directly connected to the transistor. The charge here is transferred to the transistor as a small voltage. Each transistor addressed the voltage separately, read by a frame grabber, and then stored and displayed on the screen as a digital gray value. This system requires less power to operate and is less expensive to manufacture [5].

4.3 Flat Panel Detectors

They are commonly used in extraoral imaging devices. Two approaches have been taken in selecting x-ray sensitive material for flat-panel detectors. Indirect detectors are sensitive to visible light than x-rays, so a layer of intensifying material (Gadolinium Oxybromide/Cesium iodide) is used to convert x rays energy to light. Direct detectors use a photoconductor material selenium. On applying the electric field, the electrons that are freed during x-ray exposure of "selenium" are conducted in a direct line to underlying thin-film transistor (TFT) detectors elements. The electrical energy generated is proportional to x-ray exposure and is stored at each pixel in a "CAPACITORS." These detectors are expensive and likely to be limited to specialized imaging tasks such as cone beam imaging [2].

Table 1: Classification of X-Ray films

According to sensitivity	1. Direct action / non-screen film 2. Indirect action/ screen film
According to use	1. Intraoral films 2. Extraoral films 3. Duplicating films 4. Self-developing film
According to the speed of the film	1. Slow speed film 2. Fast speed film 3. Hyperspeed G
According to packaging	1. Single film packet 2. Double film packet
According to the coating of emulsion	1. Single coated 2. Double coated

4.4 Photostimulable phosphor plates (PSP)

The Photostimulable phosphor plates (PSP) consist of a flexible polyester base with a coated crystalline emulsion of the "europium doped barium fluorohalide" compound. In order to control the infection, the plate is placed in a plastic pouch and sealed to prevent contact with oral fluids. After exposure, x-ray energy is stored in the emulsion and a latent image forms on the PSP plate, similar to the latent image that forms on a conventional emulsion. Next, the plate is placed into a laser scanner, which acts as an electronic processor. A laser beam serially scans the plate, and the stored electrons are released as visible light, which is quantified. The obtained analog signal is converted to a digital image, which is viewed on a computer screen (Figure 6). Because all the energy stored on the PSP plate is not released during scanning, it must be "erased" by exposing the plate to a strong source of light for

seconds before it is reused. PSP plates are available in similar sizes of intraoral films, as well as larger sizes for extraoral imaging [13].

4.5 Comparison of properties of image receptors

The time comparison for the acquisition of image is CCD << PSP = Film. Most conventional E speed films have a resolution of 20 Line pairs/mm, whereas with digital images have the resolution ranges from 7–10 Line Pairs/mm. The comparison of image resolution for various systems such as for Intraoral systems- Film > CCD > PSP; Panoramic systems- Film = CCD = PSP; and for Cephalometric systems: Film > CCD = PSP [2].

5. Conclusion

In this current era of dental imaging, Digital imaging has garnered enormous recognition for its cost-effective property and also in terms of quality. Though the Digital image receptors have advantages of improved visual characteristics, the conventional image receptors have their advantage of image resolution. The judicious use of these receptors always embraces the image quality and thereby providing an accurate diagnosis.

Conflicts of interest: Authors declared no conflicts of interest.

Financial support: None

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Review Article *International Journal of Dental Materials 2020; 2(1)* **e-ISSN:2582-2209**

Mineral Trioxide Aggregate: an overview of composition, properties and clinical applications

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INFORMATION

Article History

Received *21st January 2020*

Accepted *10th February 2020*

Available online *9th March* 2020

KEYWORDS

MTA

$Ca(OH)_2$

Portland cement

Fillapex

ABSTRACT

"Mineral trioxide aggregate" is a cementitious material, which is popular by its trade name MTA. MTA is a powder mixture of Portland cement clinker, bismuth oxide, and gypsum. It has gained a lot of importance in dentistry in recent years. This importance is because of its extensive use as apical restorative material as well as a medicament for Apexogenesis and Apexification treatment. As it sets by hydration process, the by products of insoluble calcium silicate hydrate and alkaline calcium hydroxide offer unique stability and potential to enhance hard tissue regeneration. This article reviewed the composition, types, properties of MTA and also its applications in the clinical dentistry.

1. Introduction

Mineral Trioxide Aggregate (MTA) was first introduced in the year 1993 by Mohmoud Torabinejad at Loma Linda University in California, USA. MTA has been used on experimental basis by many endodontists for several years. Finally, it was approved for human usage by the U.S. Food and Drug Administration [FDA] in the year 1998[1,2]. MTA appears to be an improvement over other materials for some endodontic procedures that involve root repair and bone healing. This MTA is the only material that supports overgrowth of cementum and formation of bone. MTA has both dentinogenic and osteogenic potential [3,4]. Newly developed fast-set MTAs were produced by Pozzolan cement or Zeolite cement. Pozzolan cement is a mineral aggregate with watery calcium silicate hydration. This review aimed to conduct an updated search on the composition, manipulation, types, properties, disadvantages, and clinical applications of MTA. These materials exhibit excellent biocompatibility. MTA provides better protection against microleakage than traditional endodontic repair materials which can be identified using dyes, fluid filtration and bacterial penetration leakage models [4].

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How to cite this article: Kadali N, Alla RK, Vineeth G, Ramaraju AV, Suresh Sajjan MC, Raju RV. Mineral Trioxide Aggregate: An overview of composition, properties and clinical applications. Int J Dent Mater 2020;2(1): 11-18.

2. Composition

MTA comprises Portland cement (75%), Bismuth Oxide (20%), and gypsum (5%). Portland cement is a mixture of Tricalcium silicate $(CaO)_3SiO_2$, Dicalcium silicate $(CaO)_2SiO_2$, Tricalcium aluminate $(CaO)_3\ Al_2O_3$, and Tetracalcium aluminoferrite $(CaO)_4Al_2O_3Fe_2O_3$. Various commercially available MTA materials are mentioned in table1.

3. Types of MTA

MTA is available in two different colours, including white MTA and grey MTA. The colour of the MTA depends on the concentration of FeO (black), MgO (white) and Al_2O_3. Absence of FeO in white MTA cause the change in colour from grey to white [6,7]. Compressive strength of Grey MTA is more compared to White MTA. Some MTA formulations contain, for example, MTA Fillapex (Angelus, Londrina, Brazil), resin and these are used as root canal sealing cements. The purpose of the resin addition is to improves or modifies material flow, dentine bonding, and setting time and thereby reducing the micro-leakage. However, it was found that the addition of resin to the MTA materials resulted in the reduction of the desired free $Ca(OH)_2$, which is required for root formation in immatured teeth. NeoMTA (Nusmile, Huston, USA) is a pure MTA that does not contain any resin. It enhances the cost-effectiveness of MTA and mostly used in pulpotomies [8,9,10]. The differences between grey and white MTA are described in table 2.

4. Mechanism of action

The powder of MTA consisting of inorganic particles is mixed with water; the hydration reaction starts, which is exothermic. It is a dissolution-precipitation process. As the inorganic particles dissolve in water, the nucleation growth process of calcium silicate hydrate and the precipitation of calcium hydroxide helps the hydration rate of MTA. This hydrated cement creates a calcium silicate hydrate based colloidal gel that solidifies to form an impermeable barrier with high alkalinity. As the calcium precipitate forms, the ratio of calcium silicate decreases. According to Koh et al., MTA increase the production of interleukins IL-1α, IL-1β, IL-6, IL-8. These interleukins IL-1α, IL-1β activate osteoclasts, thereby results in bone matrix production. IL-6 and IL-8 induce bone resorption and promote the development of new blood vessels. Hence, MTA is having regeneration potential of periodontal ligament and bone [11,12].

5. Manipulation

The powder is mixed with sterile water in a ratio of 3:1 (powder to liquid) to prepare MTA [13]. A metal or plastic spatula can be used for mixing on a glass slab or paper pad to form a paste of putty-like consistency. Initial mixing of the material yields a colloidal gel that finally hardens to form a solid structure [13,14]. Moisture from the surrounding tissues or wet cotton pellet supports the setting reaction. A paper point, plugger, ultrasonic condensation, or carriers with distinctive designs and messing guns can be used to deliver the MTA mix to the desired location [15]. It was found that

Table 1. Various commercially available MTA products

Products	Manufacturer
ProRoot MTA	Dentsply Tulsa Dental, Jhonson city, USA
WhitePro Root MTA	Dentsply Tulsa Dental, Jhonson city, USA
MTA-Angelus(grey)	Angelus, Londrina, Brazil
MTA-White	Angelus, Londrina, Brazil
EndoCem MTA	Maruchi, Wonju, Korea
Endoseal	Maruchi, Wonju, Korea
Retro MTA	BioMTA, Korea
MTA Fillapex	Angelus, Londrina, Brazil

using either doxycycline or chlorhexidine (CHX) instead of distilled water, did not affect on MTA's sealing ability [13,14].

6. Properties

6.1 Physical properties

These materials provide adequate working time (approximately 5 minutes), whereas the setting time is very long, which ranges from 3 to 4 hours. Therefore, $CaCl_2$, $Ca(HCO_2)_2$, and Na_2HPO_4 are used as accelerators, which can significantly decrease the setting time of MTA. However, they lower the compressive strength significantly [18,19]. On the other hand, using 2% lidocaine anaesthetic solution and saline lengthen the setting time without affecting the compressive strength. The mixing time of MTA is very crucial. The recommended mixing time is less than 4 minutes. Also, it is preferred to use the mix immediately after mixing to prevent the dehydration and drying into a sandy mixture [20].

6.2 Compressive strength

The compressive strength of MTA is around 40 MPa at 24hours, and it was reported as 67.3 MPa after 21 days. It was also reported in the literature that grey MTA exhibits more compressive strength compared to white MTA [5].

6.3 Radioopacity

Torabinejad M (1995) reported that mean radioopacity of MTA is 7.17 mm, which is equivalent to the thickness of Aluminium, and adequate to visualise radiographically [5]. Ding SJ (2008) [21] and Shah PMN (1996) [22] found that MTA has comparable radiodensity as Zinc Oxide Eugenol.

6.4 Solubility

Increased solubility was observed when MTA is mixed with more water. Buding (2008) found releasing of Ca (OH)2 when set MTA is exposed to water. The release of Ca(OH)2 is responsible for cementogenesis-inducing property [23].

Table 2. Differences between grey MTA and white MTA

Grey MTA	White MTA
Contains tetracalcium-aluminoferrite, which is responsible for grey discolouration.so, it is not used with the anterior teeth.	Ferrous oxide is replaced by magnesium oxide, so causes no tooth discolouration.
Contains large sized particles.	Contains smaller particles with narrower size distribution.
Longer setting time.	Shorter setting time.
Greater compressive strength.	Lesser compressive strength.

Table 3. Advantages and disadvantages of MTA [16,17]

Advantages	Disadvantages
• Biocompatible with peri-radicular tissues. • Non cytotoxic. • Possesses antimicrobial activity. • Non resorbable. • Excellent Sealing properties. • Very basic alkaline (high pH when mixed with water). • Facilitate regeneration of periodontal ligament.	• Treated area needs to be infection free when applying MTA, because an acidic environment will prevent MTA from setting. • Requires operator expertise. • Difficult to handle MTA as a pulp capping material due to its granular consistency, low strength and initial looseness. • Expensive.

6.5 pH

MTA has an initial pH of 10.2 that rises to 12.5 three hours after mixing.

6.6 Antibacterial and antifungal properties

Al-Hazaimi et al. (2006) reported the antibacterial activity of MTA against enterococcus faecalis and streptococcus sanguis. However, no significant antimicrobial action was observed against anaerobes [24].

6.7 Biocompatibility

Sumer *et al.* (2006) stated that MTA shows excellent biocompatibility [25]. Arens and Torobinejad (1996) treated apical perforations and osseous repair with MTA. Koh et al. proved that MTA can produce interleukins and hence provides an active substrate for the regeneration of bone cells. Kettering and Torabinejad (1995) compared MTA with Super EBA and IRM and found that MTA is not mutagenic and less cytotoxic [26].

6.8 Marginal adaptation and sealing ability

MTA exhibits excellent sealing ability as it expands during the setting reaction. So, it is advised to place a moistened cotton pellet in contact with MTA before placing permanent restoration to achieve better sealing. Valois et al. (2004) found that 4 mm thickness of MTA is adequate to ensure proper sealing [27].

6.9 Mineralisation

Holland et al. (1999) [28] theorized that the tricalcium oxide content of MTA interacts with tissue fluids and form $Ca(OH)_2$, similarly resulting in hard-tissue creation to that of $Ca(OH)_2$. Faraco *et al.* (2001) [29] concluded that the dentin bridge formed with MTA is relatively faster, with excellent structural integrity than with $Ca(OH)_2$. According to Dominguez *et al.* (2003) [30] and Tziafas (2002) [31], MTA stimulates reparative dentin formation along with maintaining the integrity of the pulp.

7. Reaction with other dental materials

MTA does not react or interfere with restorative materials [32]. Glass ionomer cements or composite resins when placed over MTA as permanent restorative materials do not affect the setting of MTA. Some interactions might occur when MTA is combined with other materials during endodontic treatment, and they are as follows;

- Chlorhexidine (CHX): Might cause difficulties for the correct setting.
- Sodium hypochlorite (NaOCl): might cause shorter setting time.
- Saline (NaCl): might cause longer setting time.
- Lignocaine: might cause longer setting time.

Advantages and disadvantages of MTA are described in table 3.

8. Clinical applications of MTA

8.1 Pulp capping

MTA has been used as a potential medicament for pulp capping with reversible pulpitis as it has excellent tissue compatibility. It is much superior to commonly used calcium hydroxide-based cements on the tissue reaction and amount of dentine bridge formed. No tissue necrosis and inflammation are seen with MTA as it is observed with calcium hydroxide. With MTA, dentin bridge formation after pulp capping was seen at about 1-week that steadily increase in length and thickness within 3-months of capping. Whereas, pulp capping with calcium hydroxide, the dentin bridge was less consistent and exhibited numerous tunnel defects. Aeinehchi et al. in 2003 reported that the formation of dentin bridge was 0.43 mm thick in 6-months with MTA, whereas it was only 0.15mm thick in 6 months when calcium hydroxide was used [33,34].

8.2 Non-vital pulpotomy

MTA was tested and found to be an ideal material with low toxic effects, increased tissue regenerating properties and excellent clinical results. The presence of blood has little impact on the setting when 2mm thick layer of MTA was placed over pulp during pulpotomy. Discolouration of teeth was observed in 60% of the deciduous molars treated with MTA. However, this discoloration of the tooth was not a problem as it would be restored with a stainless ssteel crown [34].

8.3 Vital pulpotomy (apexogenesis)

It is defined as amputation of coronal pulp completely without inserting anything into the root canal system. This procedure was done mostly for vital teeth with immature roots. Method for placement of a pulp capping, a pulpotomy is as follows [33,34];

- First, bleeding is controlled with cotton moistened with sodium hypochlorite (NaOCl).
- MTA is placed over the exposed pulp using a large amalgam carrier, and the moist cotton pellet is

placed over it.

- Then, the material is allowed to set, and the rest of the cavity is filled with a temporary filling material.
- In the next appointment that is after 1-week, the temporary filling is removed along with the cotton pellet and restored with a permanent restoration.

8.4 Root-end filling

Endodontic surgery followed by root-end filling is necessary where routine endodontic treatment is not possible. This procedure involves surgical exposure of the root apex, root resection, and plugging the apical foramen with a suitable material that provides a complete apical seal which is non-toxic, non-resorbable, dimensionally stable and radio-opaque. Numerous materials have been used as root-end filling agents, but they fail to prevent leakage. Amalgam most commonly used proved to be much inferior when tested with MTA. MTA treated teeth show less inflammation, more cementum formation and regeneration of periradicular tissues. The procedure includes the following steps [33,34,35];

- The flap is raised under local anaesthesia, followed by ostectomy, root-end resection and hemorrhage control.
- MTA is placed into the root end cavity with a small carrier and packed into place with a plugger.
- The moist environment can be created by inducing mild bleeding from the adjacent tissues and bringing the blood over MTA as placement of wet cotton is not possible.
- The area should not be rinsed after placement of MTA.
- The flap is then sutured back into place.

8.5 Apical plug (apexification of immature roots)

The purpose of apexification is to obtain an apical barrier to prevent the extrusion of the obturating material. When calcium hydroxide is used, it may take about 3 to 54 months for the completion of the procedure, which showed a significant reduction in fracture resistance. This problem is solved with the use of MTA [34,35,36, 37]. An MTA plug of 4mm thickness is adequate to form a barrier that seals the periapical area. Steps involved in apical plug formation are as follows;

- An access opening is done under local anaesthesia, and the root canal is cleaned with intracanal irrigants.
- Calcium hydroxide paste can be placed in the canal to disinfect for about 1-week. It can be removed by rinsing, and excess moisture is removed from the canal.
- Mixed MTA is placed in the cavity using a large amalgam carrier. The material is pushed towards the apical foramen with a plugger or paper points.
- The apical plug should be at least 4mm thick, and this should be checked radiographically. If not placed in adequate thickness, the entire material is rinsed and the procedure repeated.
- A moist cotton pellet is placed in the canal and tooth is restored with a temporary restoration.
- After 3 hours, the remaining canal is obturated with gutta-percha, and a permanent restoration should be placed.

8.6 Obturation of the canal

MTA can be used to obturate the root canal of a retained primary tooth where the erupting permanent tooth is absent. This material is not recommended for the obturation of primary teeth that are expected to exfoliate since it is anticipated that MTA will be absorbed slowly, if at all used [33,34].

8.7. Repair of perforation

For repairing, the clinicians need a material that should be biocompatible, should withstand moisture without dissolving and should have the excellent sealing ability. MTA can also be used for the treatment of perforation that may be caused by an iatrogenic cause or complication of internal resorption [36,38,39].

8.8 Repair of fracture

8.8.1 Horizontal root fracture

The success rate of the fracture treatment depends on the location (cervical, middle, apical) where it occurs. The root fracture located in the cervical and middle thirds causes difficulty for dental immobilization, leading to injury or even preventing the consolidation of the fragments. For these cases, it is possible to strengthen the tooth with an intra-canal pin cemented with MTA. The canal is instrumented, and then an apical plug with MTA is performed. A metal pin is selected in order to remain adjusted in the canal that is filled with MTA, and the pin is seated inside. Thus, there is reinforcement for the root, preventing mobility of the coronary segment [40-44].

8.8.2 Vertical root fracture

To repair the vertical fracture, remove the root canal filling material from the treated roots and bond the pieces internally with composite bonded resin. After raising the flap, groove the entire vertical fracture to the composite with a small bur under constant water spray. Place MTA in the groove, cover it with a resorbable membrane, and suture the soft tissue flap. To improve the prognosis of these cases, the patient should be instructed to follow meticulous oral hygiene and the treated tooth should not be probed for at least 12 weeks [45].

9. Conclusion

MTA is one of the most promising material to enter the dominion of endodontics in the last few years. MTA is a unique material with various advantages. It has been used successfully in a variety of clinical applications. However, drawbacks, especially high cost, discolouration, difficulty in handling and long setting time cannot be overlooked. Nowadays, Novel Tri-calcium silicate-based materials overcome MTA'S key applications in which it has been used with the recent introduction of new, improved MTA products. MTA based materials are still most widely used because of their superior characteristics and regeneration capacity.

Conflicts of interest: Authors declared no conflicts of interest.

Financial support: None

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Review Article International Journal of Dental Materials 2020; 2(1) e-ISSN:2582-2209

Fluoride releasing restorative materials: a review

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INFORMATION

Article History

Received *9th February 2020*
Accepted *17th February 2020*
Available online
9th March 2020

ABSTRACT

Fluoride compounds are incorporated as anticariogenic agents in numerous restorative materials. Incorporation of fluoride into restorative materials impart anticariogenic character by various mechanisms including reduction of demineralisation, enhancement of remineralisation, interference of pellicle and plaque and inhibition of microbial growth and metabolism. In addition, the application of the topical fluoride in the form of toothpaste and varnish is also considered as the most effective method of caries prevention. The fluoride combines with HA of the tooth and forms an acid-resistant fluorapatite (FAP) crystals. Also, fluoride enters into the cells of the bacteria and inhibits carbohydrate metabolism, which eventually kills the bacteria. The objective of this review was to emphasise the fluoride-releasing restorative materials available in dentistry.

KEYWORDS

Anticariogenic property

Fluoride release

Glass ionomer cement

Composites

Amalgam

1. Introduction

Dental caries is one of the most common and prevalent diseases occurring in humans across the globe [1-6]. Dental caries is an infectious disease of the dentition characterized by localized destruction of the tooth. Numerous microorganisms reside in the saliva and on the natural tooth may produce various acids that result in demineralisation of the tooth tissues. This demineralisation may be initiated in the form of a small lesion and will be progressed towards the inner tooth tissues. Pulpal necrosis might take place if this caries reaches to the pulpal tissue. The infection may be advanced into the underlying periodontal tissue through the root apex, causing periapical abscesses. The major factors, which influence dental caries, though it is a multifactorial disease, are the host such as the teeth and saliva; the microorganisms which produce acids on the tooth surface; and consumption of the fermentable carbohydrate diet [7].

The tooth is a composite structure that is composed of the phosphate-based mineral HA in the enamel, collagen in the dentine, and living tissues [8-10]. The enamel of the tooth may develop high resistance to localized demineralisation on its exposure to food, various drinks, and the microorganisms of the mouth [11-14]. However, demineralization of the natural tooth may be initiated when the pH of the oral cavity is decreased. This decrease in pH encourages the chemical

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How to cite this article: Neti B, Sayana G, Muddala L, Mantena SR, Yarram A, Harsha GVD. Fluoride releasing restorative materials: a review. Int J Dent Mater 2020;2(1): 19-23.

dissolution of both the organic and inorganic matrix components of the tooth. During this, Ca+2 and PO4+3 move away from the enamel surface and initiates demineralization [15]. The water content of enamel and dentine would facilitate acid diffusion in and mineral content out of tooth [16].

On the other hand, increase in the pH of the oral cavity towards neutrality, availability of fluoride ions (very minimal quantity), maintaining of proper oral hygiene and additional supplements of fluoride ions may help in remineralising the tissue surfaces.

Saliva, especially, is a significant source for calcium and phosphate that helps in maintaining supersaturation with respect to tooth minerals, therefore inhibiting tooth demineralization during periods of low pH, and they promote tooth remineralization when the pH returns to a neutral state. Furthermore, saliva also possesses cleansing effect and imparts antibacterial action [17].

Fluoride is well documented as an anticariogenic agent. A variety of mechanisms are involved in the anticariogenic effect of fluoride, including reduction of demineralisation, enhancement of remineralisation, interference of pellicle and plaque and inhibition of microbial growth and metabolism. Application of the topical fluoride in the form of toothpaste and varnish is considered as the most effective method of caries prevention. The fluoride combines with HA of the tooth and forms an acid-resistant fluorapatite (FAP) crystals. In addition, fluoride also enters into the cells of the bacteria and inhibits carbohydrate metabolism, which eventually kills the bacteria. The former mechanism of anticariogenic property is called as a Physicochemical method, and the latter is termed as a biological method in arresting caries [18]. Numerous researchers investigated the effect of incorporation of fluorides into various restorative materials on their anticariogenic property and remineralisation of the natural tooth. Currently, various restorative materials including traditional glass ionomer cements (GICs), high viscosity GICs, cermet cements, resin-modified glass ionomer cements (RMGICs), nano-ionomer cements, compomers, glass carbomers, giomers; and composite resins contain fluorides and they exhibit anticariogenic property. These restorative materials release an adequate amount of fluoride into the oral environment and increase the level of fluoride in saliva, plaque and hard dental tissues [18,19]. This review emphasises on the contemporary fluoride-releasing restorative materials used in dentistry.

2. Fluoride Releasing restorative materials

2.1 Glass Ionomer cements

Glass ionomer cements (GICs) were developed to utilise the advantages of both silicate and polycarboxylate cements by Wilson and Kent in 1969. Glass ionomer materials available in the form of alumino-fluoro-silicate glass powder and an aqueous solution of polyacrylic acid [20]. Traditional GICs undergo an acid-base reaction on mixing the glass powder with the liquid. Glass releases various ionic constituents during the setting reaction, including fluoride. Two processes have been proposed to describe the mechanism of fluoride release from glass-ionomers into an aqueous environment. The first process is a short-term reaction in which the outer surfaces of alumino-fluoro-silicate glass particles rapidly dissolves into solution. In contrast, in the second process, there is more gradual dissolution and resulted in the sustained diffusion of ions through the bulk cement [21-23].

During the setting reaction, an initial burst of fluoride release may be observed from the glass particles, and this release is very high over the first 24 hours. It was reported that the contemporary GICs release maximum fluoride during the first 24–48h [24–27]. Numerous studies estimated that the amount of fluoride released was in the range of 5 to 155ppm [25-28]. Bell et al. [28] evaluated the released fluoride from GICs into artificial saliva at different time intervals. They reported that the GICs released 1.0 ppm of fluoride within 10 min after immersion and the cumulative total fluoride release was 15 ppm in the first 24 hours. However, the initial burst of fluoride release may slow down over a period, and a sustained release of fluoride in lower concentrations might occur in GICs. Several in vitro studies reported the long-term fluoride release from glass-ionomers from a period of few months to a maximum period of three years [29-31].

2.2 Modified glass ionomer cements

Metal-reinforced glass-ionomers release less fluoride content compared to conventional glass-ionomer cements [29, 32-34]. This less release in fluoride content can be attributed to the availability of less fluoride as it may be replaced by the silver or due to the formation of silver fluoride which binds the fluoride ions into the cement that prevents the release of the fluoride [35].

Resin-modified glass-ionomer cements (RMGICs) were developed to address the problems of moisture sensitivity and low initial mechanical strengths typical for conventional glass-ionomers [18]. Both conventional and RMGICs were found to have a similar pattern of fluoride release from them. Several studies showed the maximum amount of fluoride release (5–35µg/cm2) from different RMGICs during the first 24hours in various storage media [27, 36-37]. From the literature available, it can be observed that the mean concentration of fluoride release from RMGIC specimens into deionized water over the first 24hours after setting amounted from 22–65ppm for the first 6h to 3–20ppm for the 18–24h period [24]. Therefore, similar to conventional GICs, it is evident that the amount of fluoride release would be decreased as the restoration is ageing.

On the other hand, polyacid modified composite (Compomer) does not show initial fluoride release burst effect [26,27,39] as shown by conventional and RMGICs. However, the levels of fluoride release remain relatively constant over time [26]. This can be attributed to a more tightly bound and/or less hydrophilic matrix of the composite resin [40], and fluoride is tightly bound to the filler particles, which are enclosed in the polymer matrix [37]. Polyacid-modified composites containing glass fillers and ytterbium trifluoride are reported to release significant amounts of fluoride than those containing Strontium fluoride [25,41-44].

Giomers are the new group of materials developed in glass ionomer cements family. As compomers, giomers also do not show an initial 'burst' effect of fluoride release. The amounts of fluoride release from the giomers are considered less than the conventional glass ionomers, but, significantly more than the compomers and composite [26, 45].

2.3 Composites

Resin-based composites are widely used in dentistry for various applications. Composites are composed of the resin matrix, filler particles and coupling agents [18, 46-48]. Earlier composites do not possess anticariogenic effect as they do not contain fluorides. However, recently developed composite formulations contain fluorides either in the form of inorganic salts or leachable glasses or organic fluoride. The amount and rate of fluoride release from these composites depend on the type of fluoride, amount of fluoride, the size of fluoridated filler particles and the hydrophilicity of the polymer matrix [48-51]. It was reported in the literature that the fluoride release from composites is lower compared to fluoride released from conventional GIC, RMGIC and compomers [25,31,37,40,52].

2.4 Amalgam

Amalgam is a direct metallic restoration, and it is an alloy of mercury with silver, tin, and copper [18]. Numerous studies investigated the amount of fluoride released from amalgam [53-55]. Several *in vitro* studies showed that the amalgam restorations release very fewer fluoride levels compared to conventional and modified GICs [53, 54]. Garcia-Godoy F et al. reported very less amount of fluoride release from amalgam restoration (less than 0.02ppm) within four weeks [55].

3. Conclusion

Fluoride released from restorative materials effectively prevent the formation of secondary caries. Fluoride levels from various restorative materials may vary depending on the type and amount of fluoride incorporated into the restorative materials formulations. However, fluoride release from different fluoridated restorative materials may decrease on the ageing of restoration.

Conflicts of interest: Authors declared no conflicts of interest.

Financial support: None

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Review Article International Journal of Dental Materials 2020; 2(1) e-ISSN:2582-2209

Augmenting realm of 3D printing in restorative dentistry and endodontics: a review

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INFORMATION

Article History

Received *2nd February 2020*

Received revised *6th March 2020*

Accepted *6th March* 2020

Available online *9th March* 2020

KEYWORDS

3D printing

CAD-CAM

Fused deposition modelling

Stereolithography

ABSTRACT

The 3D printing is entrenching itself as an advancing forefront in the field of dentistry. The 3D printing technology mostly works on the concept of additive manufacturing, which has its advantages over in contrast to the subtractive manufacturing process. Advancement of this technology has improved diagnostic accuracy, easy treatment delivery and reduced chair side time allowing the dentist to provide treatment effectively and with high precision. Educational programs which utilise 3D printed models stimulate better training of dental skills in students and trainees. Thus, 3D printing enables to provide a holistic approach to ameliorate the health and wellbeing of patients. This review article provides an overview of different methods of 3D Printing and its applications focusing on Restorative dentistry and Endodontics.

1. Introduction

Digitalization through 3D printing is a remarkable advancement in the field of dentistry which allows precision in treating patients. It is as an emerging technology with its wide variety of applications in the dental field. In the present Era, this technology ensures quality and quantity in dental care, making it a preferred modality of treatment [1].

Charles Hull printed a three-dimensional object in 1983 for the first time. He then invented the first 3D printer which he named “stereolithography”. Initially, 3D printing has been encompassing the fields of architecture, aeronautics and telecommunications. Later its application in the medical and dental field became a subject of great interest leading to increased research and better results [2].

Three-dimensional (3D) printing can be precisely described as additive manufacturing (AM), rapid prototyping, layered manufacturing or solid-free form fabrication. It is the process in which, with the creation of a virtual design of the object, the three-dimensional model is sliced into multiple thin layers. These sliced 3D models are then transferred into the 3D printer of compatible brand and type via USB, SD or Wi-Fi. The 3D printer converts every slice (2D image) into a three-dimensional object. Any geometrical object can be created by this technology [1,3].

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How to cite this article: Kamat NA, Vallabhaneni S, Saraf P, Khasnis S. Augmenting realm of 3d printing in restorative dentistry and endodontics: a review. Int J Dent Mater 2020;2(1): 24-29.

1.1 How different is 3D printing from CAD-CAM technology?

CAD-CAM uses subtractive manufacturing techniques like milling, which has some limitations in relation to 3 D printing. Milling creates a large amount of raw waste material due to its unused portions of the mono -blocks which have to be discarded after milling. Also, the recycling of excess ceramic is not feasible. Microscopic cracks can be introduced in the ceramic during the process of machining due to their brittle nature. Milling tools are usually prone to heavy abrasion and wear [4].

1.2 Applications of 3D printing technology in dentistry

Its various applications in dentistry include; Fabrication of 3D printed tooth, implant-supported restorations, Composite and Ceramic esthetic inlays and onlays, Guided Endodontic interventions, Customized myofunctional appliances, Maxillofacial customised prosthesis like eye or nose prosthesis, Obturator for maxillectomy, complete Dentures, digital impressions, invisaligners orthodontic braces, Bioprinting tissue or organs and also customised 3D printed dosage delivery system. Thus, 3D printing has revolutionized dentistry while able to produce high-quality dental prosthesis with precision.

2. Review of Various methods of 3D printing

2.1 Stereolithography

Charles Hull invented Stereolithography device in the 1980s. This device became a commercially popular printer for rapid prototyping. It depends on additive manufacturing, which converts photosensitive monomer resin (liquid material) into polymer resin (solid) layer by layer by curing them using an ultraviolet light source through photopolymerization. The materials used must be photo-curable like acrylics, epoxies, fabrication of titanium implants. The self-adhesive property of the material causes the layers to bond to one another and eventually form a complete, 3D object. The dynamics involved in the procedure affect the polymerisation time and the thickness of the layer that is cured. The addition of UV absorbers can control the depth of the polymerisation. This process is used in making Implant guides and surgical stents [5,6].

2.2 Fused deposition modelling

Schott C Rump developed Fused Deposition Modelling. A thermoplastic filament material is delivered through a nozzle controlled by temperature, and the material hardens immediately within 1 sec after extrusion. The motion of material is computer-controlled, and it deposits the material is an extremely thin layer on to a subsidiary platform. Materials such as polycarbonates and polysulfones are used. The speed and the travel of the extruder, the flow of material and the size of each 'step' influence the accuracy. This deposition modelling is the process that is used by most low cost 'home' 3D printers. It is used for printing anatomical models without any complexity [7,8].

2.3 Selective laser sintering

This technology was developed by the University of Texas and brought into use since the mid-1980. A fine material powder is sintered by scanning laser, to build up structures incrementally. As a powder bed drops down, a new fine layer of material is spread uniformly over the surface. A high (60μm) level of resolution may be obtained. No support material is required as the structures that are printed are supported by the surrounding powder. It is used in areas which require high fracture toughness and mechanical strength. Selective laser sintering is used in the fabrication of anatomical study models, cutting and drilling guides, dental models, and also for engineering/design prototypes [9].

2.4 Photopolymer jetting

Light sensitive polymers are laid onto a platform from an inkjet type print head and cured layer by layer on an incrementally descending platform with the dynamic print head. A support structure is laid down in a friable support material. This technology gives the resolution of approximately 16 microns and easy access for making complex and fine detailed objects. They are useful for printing dental or anatomical study models, Implant drill guides quickly as they are less bulky. Three-dimensional Jet printers may have a single print head like a computer printer, or they may have multiple heads to cover the width of the working platform. A UV lamp or a light source is used by 3D printers to harden the resin or wax after each layer is jetted. Either the print head moves across the working platform, or the platform moves back and forth under the stationary print head. A wide range of resins, silicone rubber and waxes are used for casting .

2.5 Powder binder printer

A modified inkjet head is used to print in this printing method. The liquid droplets are allowed to infiltrate a uniform and single layer of powder one after the other. With this, the powder bed drops incrementally, and a final model is ready. This model is built of many layers and a new fine layer of powder is swept over the surface. The un-infiltrated powder will itself support the model, and so no other support material is essential. A cyanoacrylate or epoxy resin can be infiltrated during post-processing procedures to improve the strength and surface hardness. These models are fragile, and their accuracy is limited; however, they are useful as study models or visual prototypes [3,10].

2.6 Thermal inkjet / bioprinting

Ink-jet printing is a "noncontact" technique which uses thermal, electromagnetic or piezoelectric technology to deposit tiny droplets of ink onto a substrate. In inkjet printing, droplet deposition is usually done by using heat or mechanical compression to eject the ink drops. The print head is heated, which creates small air bubbles that collapse, creating pressure pulses that eject ink drops from nozzles in volumes as small as 10 to 150 picoliters. These are particularly promising for use in tissue engineering and regenerative medicine. Because of their digital precision, control, versatility, and benign effect on mammalian cells, this technology is already being applied to print simple 2D and 3D tissues and organs, also known as bioprinting. Bioprinting is used to create soft tissue scaffolds, 3-dimensional scaffolds, hydrogels, polymers [11].

3. Applications of 3d printing in restorative dentistry and endodontics

Three-dimensional printing has successfully improved the quality and precision of dental operative work. With this clinical dental practice has become easier, efficient and quick.

3.1 Reconstruction of 3d models

Dental education has always relied on extracted teeth for preclinical exercises, and these teeth provide semi-realistic clinical situations. But there is always an uncertainty in availability of all possible anomalies in those extracted teeth. The 3D printed tooth models can mimic teeth with internal, external resorption defects, open apices and those with pulp stones, dilacerations, dens in dente and many other anomalies which serve as more realistic anatomic structures, which aid in the development of endodontic skills by providing visual, acoustic and tactile proprioception and help in acquiring improved skills in minimal intervention during preclinical training. In 3D reconstruction, the 3D image of the teeth is taken, with which features of product or component are captured then they are uploaded to a computer software program, to get a copy of the same component. The desired model can be adjusted or altered as per the needed requirement and can be printed in a few hours. It reduces lead time for manufacturing rapid prototypes. Keeping in mind individual treatment objectives, a simulated 3D model of final treatment outcome can also be fabricated, for patient education and motivation which will enable patient to understand treatment options and strategy even before starting the procedure [12,13].

3.2 Fabrication of tooth restoration

The common factor of failure of restorative materials is dimensional changes at the margins, which lead to instability or total loss of dental fillings. 3D restorative materials with continuous self-folding adjustment are materials which are capable of moving toward the peripheries by changing position and shape from the centre to margins; hence they avoid microleakage or marginal overhangs. These eliminate the need for Dental adhesives (etching-bonding systems) as they rely on mechanical retention rather than chemical aids. They can also be used in inaccessible areas where manipulation of restorative materials is difficult. For Fabrication of 3D printed tooth restoration, tooth cavity preparation is done, scanning of preparation is done. It is uploaded on the computer; filling with appropriate material of choice is chosen and printed. Lastly, cementation can be done. These materials have good strength and biocompatibility and maximum adaptation. Thus, it helps in improved esthetic treatment planning and better skill acquisition [14].

3.3 Guided endodontics

It's a novel treatment approach for root canal treatment of teeth with calcified canals for gaining access using 3D printed templates. Ageing, trauma, caries or orthodontics causes progressive narrowing of root canals and during attempted location and negotiation of calcified canals perforations or gauging are implicated. Hence to avoid this, 3D guided access stents or templates are digitally designed to target burs in elusive canals. CAD software Digital impressions are merged with CBCT scans, this forms DICOM data which is then

allowed to create STL file containing bony architecture for pulp canal obliterated teeth, these structures are sliced, and the sliced data is sent to the printer where the final printed guides are obtained. 3D printed access guides are efficient and safe means for addressing challenging endodontic scenarios like malpositioned teeth or teeth with extensive restoration enabling conservation of tooth structure and minimizing chances of iatrogenic errors [15-17].

3.4 Surgical guides

Endodontic microsurgery like root-end resection and osteotomy procedures are done based upon on CBCT measurements or X-Ray. In clinical scenarios proper orientation, angulation and depth of penetration of bur are required which otherwise might cause deviation in angulation or larger diameter of osteotomy leading to human errors, increased healing time and post-operative pain which is undesirable. Surgical stent-like guides are designed that reproduces preplanned osteotomy site which can mitigate risk through avoiding encroachment upon neurovascular structures or adjacent teeth and also avoiding perforations at osteotomy sites. With these stents, more accurate, precise, localised, less invasive microsurgeries can be performed [16,17].

3.5 Auto transplantation

Successful auto transplantation requires preservation of periodontal ligament cells and adequate adaptation of transplanted tooth to the recipient site. In conventional methods, while preparation of the recipient site, multiple fitting attempts to alveolar bone are initiated that causes increased extra oral time. Any kind of trauma to PDL during the procedure profoundly influences the outcome results. Auto transplantation using 3D printing increases the chances of the tooth-saving procedure. Computer-aided rapid prototyping (CARP) is used to print a replica of the tooth such that modification of recipient bone site is done before extraction without PDL damage from repeated insertion and removal. With this recipient, the tooth can be prepared for the crown, and a temporary crown can be placed immediately after placing the tooth in the desired tooth site. This method minimises extra oral time and chances of any error during auto transplantation [18,19].

3.6 Dental pulp regeneration & fabrication of scaffolds

The 3D cell printing technique can also be utilized for replacing pulp tissue. Additive manufacturing has the capability to preserve natural tooth rather than replacing it by prosthetic surgery. Using an inkjet device by dispensing layers of cells that are suspended in the hydrogel, the structure of the pulp tissue is recreated, which mimics the natural pulp tissue of the tooth. This is achieved by systematically placing the odontoblastic cells at the periphery and fibroblasts within the core with a supportive network of vascular and neural cells. Various types of calcium phosphate cements have been developed by 3D printing to form porous customized scaffolds for regeneration of pulp dentin complex by Rapid prototyping or solid free form fabrication techniques. Polyethylene oxide and polyethylene glycol dimethacrylate photo-polymerisable hydrogels are used to fabricate scaffolds of various geometric shapes through customized tissue engineering. These 3D scaffolds are useful in repairing the defects caused by accidents, surgery or during birth [20,21].

4. Limitations of 3D printing

- High cost.
- An inherent weakness is built into the design due to its staircase effect. This effect is created by successive deposition of material on top of the first layer.
- Requires support materials, which are difficult to remove later.
- Finishing the final product is time-consuming.
- It is technique sensitive; a trained professional is required.
- Resin causes inflammation, irritation on contact or inhalation.
- Resin cannot be heat sterilized.
- Stereolithography can be done if only light-curable polymers are available.
- Depending on materials, additional treatment like sintering might be required for additional strength
- Ethical and legal clearance is low.

5. Conclusion

Procurement and availability of technical expertise and equipment within endodontic practices present formidable obstacles to widespread deployment within the endodontic speciality. The 3D printing has enormous potential to ameliorate dental care in treatment, research and education. Thus, 3D printing is successful in establishing itself as a milestone in the field of dentistry, its utility in treatment planning and analysing

Table 1. 3D Printing modalities

3D Printer	Materials	Applications	Advantages	Disadvantages
Steriolithography (SLA)	Photopolymerising Resins , Acrlyics & Epoxies.	Dental models , surgical Guides, orthodontic retainer and aligners ,crowns and bridges.	High accuracy , Good surface finish, high mechanical strength, rapid fabrication.	High cost, cannot be heat sterilized, Limited shelf life, skin irritation by resin contact or inhalation.
Fused Deposition Modelling	Thermoplastic polymers like Polylactic acid, Polycarbonate, Polyether Ether Ketone, Poly Methyl Methacrylate, Bioactive glass Composites.	Bone tissue Engineering, Craniofacial Defects , Maxillofacial Prosthetics (prototyping anatomical parts)	Most low cost 3D printer.	Limited materials – only thermoplastic materials can be used. Limited shape complexicity. FDM requires support structures to be removed.
Selective Laser sintering.	Polymer Powder such as Alumide, Polyamide, rubber like polyurethane, Metal alloys like titanium ,Co-Cr, stainless steel.	Metal crown copings , metal or resin in partial denture framework, Cutting drilling guides.	High fracture toughness and mechanical strength. Polymeric metals can be autoclaved. metallic materials can be recycled.	High cost , significant infrastructure required. messy powders with inhalation risk. Explosive Risk.
Powder Binder Printers	Plaster of paris . Pigmented water	Study models, Visual prototypes.	Low cost, relatively fast process, materials used are safe, they can print coloured 3D objects.	Low resolution. Limited Accuracy. Less strength. Difficult to heat sterilize.
Bioprinting	Alginate, ,fibrin, collagen, PLGA (poly lactic co-glycolic acid), tricalcium phosphate, chitosan, Hyaluron	It creates structure with living cells , Hard and soft tissue scaffolds, 3-dimensional hydrogels, ceramics and hydrogels.	It can be operated at room temperature. They do not require thermoplastic materials.	Distortion of cellular structure and loss of cellular viability.

improves the quality of dental treatment and patient satisfaction. The 3D printers are becoming accessible and affordable, but the skill of operator and material cost must be taken into consideration. Safety and Health protocols must also be followed. Endodontic post-graduate programs must consider implementing the 3D printing into curriculums in the near future. Further research in this would revolutionize digital dentistry and also the clinical outcomes of treatments employing the 3D printed objects.

Conflicts of interest: Authors declared no conflicts of interest.

Financial support: None

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International Journal of Dental Materials

Volume 2 Number 1 January-February 2020

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