**INTRODUCTION**

“Endodontics is that branch of dentistry that is concerned with the morphology, physiology and pathology of the human dental pulp and peri- radicular tissues. Its study and practice encompass the basic clinical sciences including biology of the normal pulp; the aetiology, diagnosis, prevention and treatment of diseases and injuries of the pulp; and associated peri-radicular conditions.”

***- American Association of Endodontists,2006***

“A gadget is a small tool such as a machine that has a particular function, but is often thought of as a novelty. “

The specialty discipline of Endodontics has progressed through many changes over the last 20 years. Most of these have been related to the technical aspects of root canal treatment. Clinicians now probably feel that they are technologically more advanced in what they are doing.

Looking back over the last two decades from 1990 – 2010, there are 3 main areas of change in root canal treatment - in a broad sense, 2 are technological, and 1 is biological. The 2 technical areas are the increasing use of nickel-titanium rotary files and the use of magnification. The biological aspect centres around the use - or rather the non-use - of intracanal medicaments and the number of treatment visits.

The focus of root canal treatment must be on the elimination of bacteria from the root canal system and from the tooth overall since pulp and periapical diseases are caused by bacteria. With this aim in mind, clinicians should question how this can be achieved and does the use of a different file help, does newer gadgets help, and do medicaments help.

Bacteria are clever! They can enter a tooth via various pathways and then can establish colonies within the tooth structure. These include the dentine

tubules, lateral canals, accessory canals, transverse anastomoses between canals, the isthmus, fins, “loops”, etc. Hence, clinicians should always remember that they are treating the “***root canal system***” and not the “root canal.” 1

There is no doubt that the technological advances in root canal treatment are favoured by many practitioners, but we should also know for what reason, particularly in the light of them not being universally accepted by all practitioners.

We are diagnosing and treating a very complex tissue system – that is, the tooth-pulp-peri-radicular complex – and within the tooth, we have a very complicated root canal system and not just a root canal! We are also dealing with very clever micro-organisms that have the incredible ability to colonize parts of the tooth that we cannot see (even with magnification!) or treat mechanically. These micro-organisms can also adapt to changes in the environment and survive within the root canal system despite our best efforts at times. Our aim must be to eliminate them and create an unfavourable environment in which they cannot survive. The mechanics and newer technology may help.

The move from film to digital radiographs, more profound local anaesthetics delivery systems, standardization of endodontic instruments, and new instrument alloys with novel geometric designs, newer gadgets are a few of the advances over the years. There are now many exciting developments to improve the quality and the output of our endeavours; some of them will be

„„winners‟‟ and some will be losers. Time and experimentation will determine which is which.2

Current studies show that both endodontically treated teeth and single-tooth implants have similar outcomes. Thus, healthy maintenance of the natural tooth should remain the overall goal.

Hence, this dissertation on “Gadgets in Endodontics” will give us an idea about various old and new endodontic gadgets which helps us to achieve the most effective way of successful root canal treatment.

## PULPAL DIAGNOSIS

Diagnosis is the art and science of detecting and distinguishing deviations from health and the cause and nature thereof. The purpose of a diagnosis is to determine what problem the patient is having and why the patient is having that problem. Ultimately, this will directly relate to what treatment, if any, will be necessary. No appropriate treatment recommendation can be made until all of the whys are answered. Therefore, careful data gathering as well as a planned, methodical, and systematic approach to this investigatory process is crucial.

Diagnosis of the health of the pulp and pulp-related dental pain are problematic, and may lead to difficulties in planning treatment.2 If pathosis is present, pulp testing combined with information taken from the history, examination, and other investigations such as radiographs leads to the diagnosis of the underlying disease which can usually be reached relatively easily.

Key uses of pulp testing in clinical practice:

1. prior to restorative, endodontic, and orthodontic procedures
2. as a follow-up and for monitoring the pulp after trauma to the teeth
3. in differential diagnoses, such as excluding periapical pathosis of pulp origin.
4. assessment of anesthesia

The ideal pulp test method should provide a simple, objective, standardized, reproducible, nonpainful, non-injurious, accurate and inexpensive way of assessing the condition of the pulp tissue.3

### In endodontics, pulp testing is done by-

1. thermal
2. electric pulp testing (EPT)
3. special tests- ( bite test, test cavity, selective anesthesia)

‗Pulp vitality‘ implies blood supply, which thermal and electric tests do not confirm. Further information when attempting to diagnose the condition of the

pulp may come from appropriate radiographs, blood flow tests such as laser Doppler flowmetry if available, preparation of test cavities and anaesthetic tests. However, none of the current pulp testing methods meets all criteria.3,4

### Pulpal innervation4

It is important to have an understanding of pulpal innervation characteristics in order to appreciate the rationale for, and mechanisms involved in, tests of pulpal sensitivity.

In the pulp chamber coronal nerve bundles diverge and branch out towards the pulpo-dentine border. Nerve divergence continues until each bundle loses its integrity and smaller fibre groups travel towards the dentine. This route is relatively straight until the nerve fibres form a loop resulting in a mesh that is termed the plexus of Rashkow. Terminal axons exit from their Schwann cell investiture and pass between the odontoblasts as free nerve endings. This nerve plexus is most well developed in the peripheral pulp along the lateral wall of coronal and cervical dentine, and along the occlusal aspect of the pulp chamber. Two types of sensory fibres are present in the pulp, the myelinated (A fibres) and unmyelinated C fibres.



### Fig: 1 Schematic drawing illustrating the location of A and C fibres in the dental pulp

The A fibres predominantly innervate the dentine and are grouped according to their diameter and conduction velocities into A-beta and A-delta fibres. The

A-beta fibres may be more sensitive to stimulation than the A-delta fibres, but functionally these fibres are grouped together.

The C fibres innervate the body of the pulp. The A-delta fibres have lower electrical thresholds than the C fibres and respond to a number of stimuli which do not activate C fibres.

A-delta fibres mediate acute, sharp pain and are excited by hydro-mechanical events in dentinal tubules such as drilling or air-drying.

The C fibres mediate a dull, burning, and poorly located pain, and are activated only by stimuli reaching the pulp proper. C fibres have a high threshold and can be activated by intense heating or cooling of the tooth crown. Once activated, the pain initiated by C fibres can radiate throughout the face and jaws.

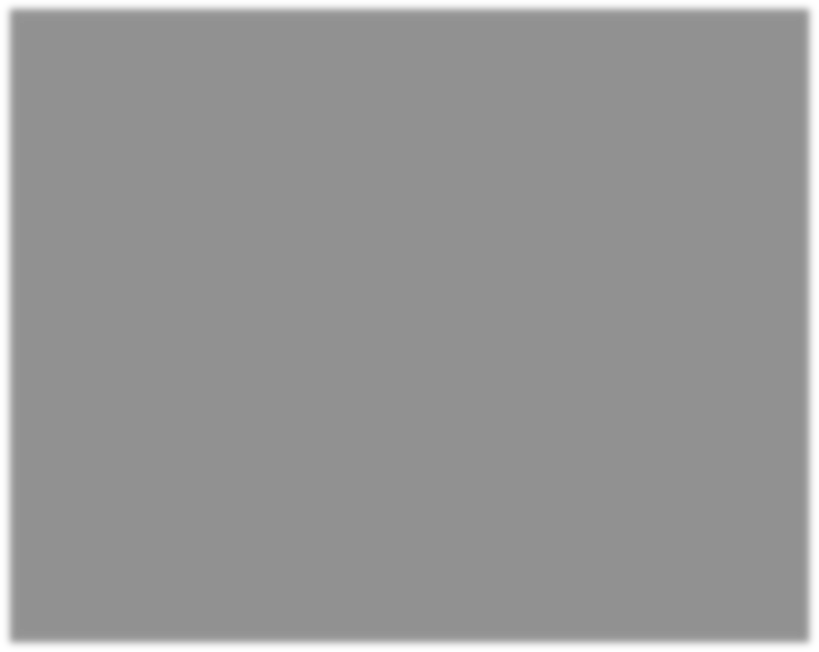
As the intensity of the stimulus increases, more sensory nerves are activated, and this results in a progressive increase in the sensory response. The response to a given stimulus will be greatest where neural density is the highest. Key variables known to affect the response to pulp testing are the thickness of the enamel and dentine, and the number of nerve fibres in the underlying pulp.

Lilja *et al* found that the highest concentration of neural elements was in the pulp horn region. A progressive decrease in the number of nerve fibres in the cervical and radicular areas was observed. Similar findings were reported by Byers and Dong.

The direction of the dentinal tubules is also important in establishing pulp test responses in various parts of the tooth crown. The dentinal tubules run an almost straight course from the incisal edge of anterior teeth to the pulp horn. In multi-cuspal teeth, the course of tubules is somewhat curved and resembles an ‗S‘ shape. Because it is principally the fluid in the tubules that conducts electrical impulses from the pulp tester electrode to the pulp, the shorter the distance between the electrode and the pulp, the lower the resistance to the flow of current.

### a. Electric pulp test

Assessment of pulp neural responses (vitality) can also be accomplished by electric pulp testing. Electric pulp testers of different designs and manufacturers have been used for this purpose. Electric pulp testers should be an integral part of any dental practice. It should be noted that the vitality of the pulp is determined by the intactness and health of the vascular supply, not by the status of the pulpal nerve fibres.3,5



### History5

**Fig:2 Waldent Electric Pulp Tester**

* The use of electricity in dentistry is attributed to Magitot and described in his book Treatise on Dental Caries published in France in 1867 (cited in Prinz 1919). Magitot advocated the use of an induction current to localize carious teeth.
* Later, Marshall (1891) and Woodward in 1896 (cited in Prinz 1919) used electricity to demonstrate vital and nonvital pulps.
* In 1896, Woodward found the following: If a few cells of a cataphoretic apparatus are in action, and the positive electrode be applied to the dentine or metallic filling in a vital tooth, while the negative pole is at the cheek or wrist of the patient, a distinct sensation should be felt, while in the case of a dead pulp there will be no response; usually even a small filling

will transmit a distinct shock in a vital tooth, which is absent in a devitalised tooth.

* However, Roentgen in 1895 was probably the first to introduce the use of electricity clinically for diagnosing diseases of the pulp (Grossman 1976).
* In 1901, investigators in Europe attempted to standardize the instrument used for electrical stimulation of the dental pulp. In the same year, Futy used a device where the primary current of an induction coil fed two electrodes. One was held in the patient‘s hand, and the other applied to the tooth with a platinum pin covered with water-saturated cotton. Up to 2 V were applied, controlled with a rheostat.
* In 1907, Hafner made a similar observation regarding the effects of the electric current on vital and devitalized teeth using alternating and direct current. An instrument with two electrodes was controlled with a rheostat supplying up to 5 V. In order to obtain the most accurate interpretation, he used another tooth as a control. This control tooth was presumed to be normal, and was anatomically similar to the tooth under test. A rubber dam was applied. Hafner found that the diseased tooth either did not respond to a large amount of current, or else responded violently to a comparatively small amount of current that had no effect on the control tooth. He interpreted these findings as suggesting that the pulp of the problem tooth was either dead or inflamed.
* The usefulness of electric pulp tests became a topic of controversy for decades.
* In the 1970s EPT regained popularity when new designs of instrument were introduced. Several studies claiming advantages and disadvantages were published. There were two electric testing modes-

1. bipolar
2. monopolar

They were further divided in to two subclasses-

1. with mains connection
2. those using batteries

However, the most common types are battery operated. Prior to the mid- 1950s bipolar instruments were used, while almost all testers in use today are monopolar.

* + Bipolar testing- involves placing two electrodes on the tooth, one on the buccal surface and the other on the palatal/lingual surface, with current passing through the crown from one electrode to the other.
  + Monopolar testing involves only one electrode applied to the tooth. The patient completes the electric circuit by holding the metallic handle of the EPT, or a lip clip is applied. Monopolar and bipolar testers are based on the production of impulses of negative polarity.

### Mechanism4

The objective of EPT is to stimulate intact Aδ nerves in the pulp–dentine complex by applying an electric current on the tooth surface. A positive result stems from an ionic shift in the dentinal fluid within the tubules causing local depolarization and subsequent generation of an action potential from intact Aδ nerves.

### Optimal placement of the tester electrode-

The response threshold is reached when an adequate number of nerve terminals are activated to attain, what is termed a summation effect. An area of high neural density should have a relatively fast and strong response, and requires the least electric current.5

So, for-

* + incisor teeth- at the incisal third region, where the enamel is thinnest or absent.
  + posterior teeth- mid third region.



### Fig:3 Optimum site for tester electrode placement on incisors is at the incisal third region

**Steps involved4**

1. The electric pulp tester is a battery-operated instrument, which is connected to a probe that is applied to the tooth under investigation.
2. The probe tip will be coated with a conducive medium such as toothpaste and placed in contact with the tooth surface.
3. The evaluated teeth is to be carefully isolated and dried. A control tooth of similar tooth type and location in the arch should be tested first in order to establish a baseline response and to inform the patient as to what a ―normal‖ sensation is.
4. The patient will activate the unit by placing a finger on the metal shaft of the probe to complete the electric circuit; however, the use of lip clips is an alternative to having patients hold the tester. It functions by producing a pulsating electrical stimulus, the initial intensity of which should be at a very low value to prevent excessive stimulation and discomfort.
5. The intensity of the electric stimulus is then increased steadily at a pre- selected rate, and a note is made of the read-out on the digital display when the patient acknowledges a warm or tingling sensation.

Peak of stimulus current reaction numerical value.

* + Between 0-40, the patient feels ache and anesthesia, it means alive tooth nerve.
  + Between 40-80, with above mentioned reaction, if means part of tooth nerve dead.
  + 80, no above-mentioned reaction dead tooth nerve.

1. The read-out is not a quantitative measurement of pulp health, but simply provides evidence that the Aδ fibres are sufficiently healthy to function.
2. If a complete coverage crown or extensive restoration is present- Bridging technique can be attempted to deliver the electric current to any exposed natural tooth structure-
3. The tip of an endodontic explorer is coated with toothpaste or other appropriate medium and placed in contact with the natural tooth structure.
4. The tip of the electric pulp tester probe is coated with a small amount of toothpaste and placed in contact with the side of the explorer.
5. The patient completes the circuit and the testing proceeds as described previously.
6. If no natural tooth structure is available, then an alternative pulp testing method, such as cold, should be used.

### Advantages-

* It can also be helpful in diagnosing the state of a pulp in a tooth that has undergone pulp canal calcification. They are useful when these teeth do not respond to a thermal test, but respond to the EPT in the absence of a periapical radiolucency. 5

### Limitations-

* It does not provide any information about the vascular supply to the pulp, which is the true determinant of pulp vitality.
* Multi-rooted teeth may have a partially necrotic pulp and healthy pulp present in the root canal system, and these teeth are able to respond positively to testing.
* Traumatic injuries to teeth present problems with respect to vitality. Bhaskar & Rappaport (1973) described 25 traumatized anterior teeth and EPT in all cases gave a negative response. After making endodontic access the researchers found the pulps were vital and concluded that EPT did not correlate with microscopic findings following traumatic injuries. They recommended that for traumatized teeth pulps should be considered vital until proved otherwise.
* The EPT is often unreliable in testing immature permanent teeth (Fulling & Andreasen 1976, Klein 1978, Brandt et al. 1988) as full development of the plexus of Rashkow does not occur until 5 years after tooth eruption (Johnsen 1985).
* Practitioners should interpret responses to EPT cautiously in orthodontic patients; thermal testing with carbon dioxide snow may be more reliable.
* Anxious or young patients may have a premature or false-positive response due to the expectation of feeling an unpleasant sensation.
* Drugs, including narcotics and alcohol, can also influence EPT responses

Unfortunately, the interpretation of pulp test results is not a definitive procedure and all available data must be considered in reaching a diagnosis.

Petersson *et al.* (1999) described a ‗gold standard‘ method. They pulp tested 59 teeth and compared the result by direct inspection of the pulp chamber contents. They concluded that the probability of a sensitive reaction for a vital pulp was 90% with cold, 83% with heat and 84% with an EPT, and in nonvital pulp it was 89% with cold, 48% with heat and 88% with the EPT. The accuracy was 86% for the cold test, 71% for heat and 81% for the EPT (Petersson *et al*. 1999). This indicates that cold and the EPT are reliable to a similar extent in the diagnosis of vital and nonvital pulps.6,7

### Laser Doppler Flowmetry (LDF)

It was developed for measurement of blood flow in microvascular systems,

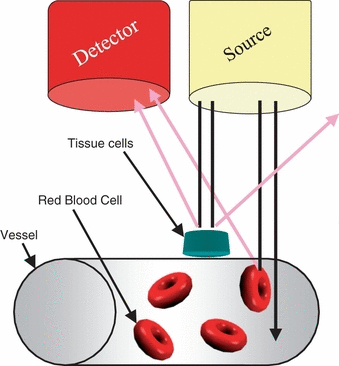
e.g. the retina, renal cortex and skin. It‘s use in teeth was first described by Gazelius and co-workers in 1986.7



### Fig:4 Laser Doppler Monitor (MOORS Instruments) Mechanism-

The technique is widely used to monitor dynamic changes in pulpal blood flow in response to pressure changes and following administration of local anaesthesia.

* 1. The technique utilizes a beam of infrared light produced by a laser that is directed into the tissue.
  2. As light enters the tissue, it is scattered and adsorbed by moving red blood cells and stationary tissue elements.
  3. Photons that interact with moving red blood cells are scattered and frequently shifted according to the Doppler principle.
  4. Photons that interact with stationary elements are scattered but are not Doppler shifted. A portion of the light is returned to the photon detector, and a signal is produced. Because red blood cells represent the vast majority of moving objects within the tooth pulp, measurement of Doppler-shifted backscattered light is interpreted as an index of pulpal blood flow.8



**Fig:5 Doppler mechanism**

Due to the pulsatile nature of blood flow, many studies, have observed that LDF recordings in teeth with intact pulp blood flow have rhythmic fluctuations or oscillations.

### Indications9

* Estimation of the pulpal vitality
* Pulp testing in children: sensibility tests are not reliable in children, because they are subjective and rely upon the patient response. LDF may be a better choice
* To monitor age related changes in PBF.
* Monitoring of revascularization of replanted teeth
* Monitoring reactions to orthodontic procedures.

### Advantage

* Accurate
* Reliable
* Non-painful
* Luxation injuries
* Useful in young children whose response are un-reliable

The collected data are based on objective findings rather than subjective patient responses.8,9

### Factors influencing the results 9,10

1. Characteristics of the laser beam -

Many variables regarding the characteristics of laser beams have been found to significantly affect the Flux signal recorded from dental pulps. These include the choice of bandwidth filter (Odor *et al.* 1996), the wavelength of the laser source (Odor *et al.* 1996), and the fibre separation within the probe (Ingo´lfsson *et al*. 1993, Odor *et al.* 1996). Studies comparing some of these variables have supported the use of a narrow, 3 kHz bandwidth filter rather than a 20 kHz bandwidth filter (Odor *et al*. 1996, Roebuck *et al*. 2000) and the use of a 810 nm (Odor *et al.* 1996a) or a 633 nm laser source (Roebuck *et al.* 2000).

1. Probe position-

Some studies (Ramsay *et al*. 1991, Hartmann *et al*. 1996) have noted higher Flux values being obtained from vital teeth as the probe was moved closer to the gingival margin, but moving the probe closer to this area may increase the possibility of including non-pulpal signals from the periodontal tissues.

1. Application of medications-

Pulpal blood flow can change in response to the application of capsaicin to the adjacent gingival or alveolar mucosa (Verdickt & Abbott 2001) or consuming anti-hypertensive medications and nicotine (Musselwhite *et al.* 1997).

### Limitations 10,11

* + Motion artefact due to uncontrolled movement of the probe when placed against the tooth. Thus, there may be a need for a modified mouth-guard or splint to stabilize the measuring probe on the tooth

surface in order to obtain more accurate and reproducible readings.

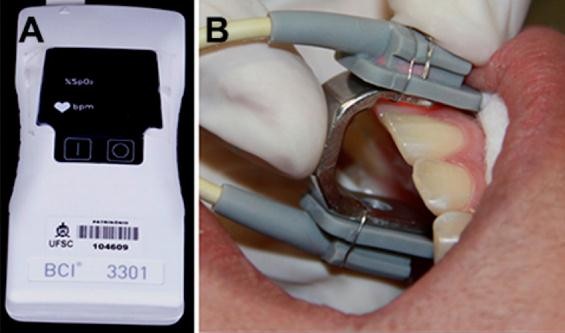
* + Blood pigments within a discoloured tooth crown can also interfere with laser light transmission. Care must also be taken to ensure that the false positive results are not obtained from the stimulation of supporting tissues.
  + Any obstruction and/or interference of the light pathway can render LDF useless—examples being restorations, especially if they are full coverage crowns.
  + Too expensive for a device to be used in dental practice.

It is not being routinely used in dental practice.

### Pulp Oximetry-

This is an oxygen saturation monitoring device widely used in medical practice for recording blood oxygen saturation levels during the administration of intravenous anaesthesia.

In 1940, Squire recognized that changes of red and infrared light transmission caused by pneumatic tissue compression permitted saturation to be computed. In 1950, Wood used this idea to compute absolute saturation continuously from the ratios of optical density changes with pressure in an ear oximeter. Takuo Aoyagi, an electrical engineer at Nihon Kohden company in Tokyo, realized that the pulsatile changes of oxygen saturation could be used to compute saturation from the ratio of ratios of pulse changes in the red and infrared.His ideas, equations, and instrument were adapted, improved, and successfully marketed by Minolta about 1978, stimulating other firms to further improve and market pulse oximeters worldwide in the mid- 1980s.



### Fig:6 a) Pulse oximeter b) sensor with specially manufactured adapter

**Mechanism8,12**

The pulse oximeter sensor consists of two light-emitting diodes-

* 1. To transmit red light (640 nm)
  2. To transmit infrared light (940 nm)
  3. a photodetector on the opposite side of the vascular bed

The light-emitting diode transmits light through a vascular bed such as the finger or ear. Oxygenated haemoglobin and deoxygenated haemoglobin absorb different amounts of red/infrared light. The pulsatile change in the blood volume causes periodic changes in the amount of red/ infrared light absorbed by the vascular bed before reaching the photodetector. The relationship between the pulsatile change in the absorption of red light and the pulsatile change in the absorption of infrared light is analysed by the pulse oximeter to determine the saturation of arterial blood.

Kahan and co-investigators subsequently developed a customized probe, in conjunction with a commercial pulse oximeter, for pulp vitality testing. Unfortunately, the accuracy of the commercial instrument was disappointing, and was not considered to have predictable diagnostic value.

The average value of the measurement of all the teeth is 84%.

The average saturation measured on the small finger of the right hand of the patient is 98%.

### The critical requirement of using pulse oximeter in dentistry-

* Sensor should conform to the size, shape, and anatomical contours of teeth.
* Sensor holder should keep the light-emitting diode sensor and the photoreceptor as parallel as possible to each other so that the photoreceptor sensor receives the light transmitted through the tooth.12

### Advantage-

Compared to laser Doppler flowmeters, pulse oximeters are relatively inexpensive.

### Limitations-

1. For pulse oximetry to be accurate, however, a normal arterial blood flow is required. When arterial pulsatile blood flow is low, pulse oximeter measurements are unobtainable. This may occur during hypovolaemia, hypothermia, or intense peripheral vasoconstriction.
2. It may have lower specificity in cases where the coronal pulp is undergoing calcific changes. In such cases, a radicular vital pulp with coronal calcification could potentially cause a false negative response.

Investigators have concluded that the devices used for pulp testing are too cumbersome and complicated to be used on a routine basis in a dental practice.7

### Spectrophotometry

It uses dual wavelength lights in an effort to ascertain the contents of enclosed spaces such as the pulp chamber. Diffusion wave spectroscopy was introduced by W.L. Butler in 1962 for measuring minute absorption changes of highly turbid biological materials *in vivo.*

It has been tested with optimistic, but only initial, experimental results. The spectrophotometer technology is not nerve dependent. Measurement of pulp oxygenation level depends on the blood supply. A spectrophotometer determines oxygenation blood level changes.14



### Fig:7 Crystaleye Spectrophotometer

Nissan *et al*. did an *in vitro* study to determine the feasibility of using DWS to identify teeth with pulp chambers that are either empty, filled with fixed pulp tissue or filled with oxygenated blood. Their findings indicated that continuous- wave spectrophotometry may be a useful method for testing pulp vitality.

### Advantages-

1. It uses visible light that is filtered and guided to the tooth by fibre optics. Thus, unlike Laser light, added eye protection is unnecessary for the patient and the operator.
2. Influence of the gingival circulation cannot be ruled out and data on how large a mass of pulp tissue is needed for accurate readings must be determined.
3. It is non-invasive and yields objective results.
4. It is small, portable, relatively inexpensive and should be suitable for use in a private dental office.

### Photoplethysmography

It is an analysis of the optical property of a selected tissue. It was developed for pulp testing in an attempt to improve pulse oximetry, by adding a light with a shorter wavelength. The results, whilst promising, were nonetheless equivocal. 3,8



### Fig:8 Multiwavelength optical plethysmograph.

The basic form of PPG technology requires only a few opto-electronic components:

1. a light source to illuminate the tissue (e.g., skin or tooth)
2. a photodetector to measure the small variations in light intensity associated with changes in perfusion in the catchment (study) volume.

The PPG sensing technology has been substantially improved since its origins in 1937.

PPG has been compared with LDF in experiments on skin and was found to be of similar value.

It is proposed that circulatory changes in human dental pulp can also be investigated with the PPG technique. Haemoglobin absorbs certain wavelengths of light, while the remaining light passes through the tooth and is detected by a receptor. The heart rate variability is composed of low- and high-frequency fluctuations, which are mediated by the sympathetic and the parasympathetic nervous systems. The baseline and the amplitude of the PPG signal also show fluctuations in the same frequencies. PPG assessments of dental pulp tissue viability have demonstrated pulsatile waveforms synchronous with a finger PPG reference in healthy subjects and the loss of pulsatility in patients with nonvital dental pulp. There was a significant negative correlation between the tooth PPG signal and subject age in those with healthy teeth.3,

### Transmitted Laser Light (TLL)

It is an experimental variation to LDF, aimed at eliminating the non-pulp signals. TLL uses similar sending/receiving probes as conventional LDF, but the probes are separate. Thus, the laser beam is passed through from the labial or buccal side of the tooth to the receiver probe which is situated on the palatal or lingual side of the tooth.

### Limitations

Same as with any laser technology where obstruction and/or interference from within the tooth structure will affect the results.2,3

**MOBILOMETER**

Human teeth are not anchored directly into the alveolar bone. The periodontal ligament connects the tooth to the bone. Tooth mobility is considered as one of the important signs in the diagnosis of periodontal and endodontic diseases. In spite of many recent advances in understanding the role of tooth mobility, its function and significance are still questionable in the study of periodontal physiology. Loosening of a tooth is considered as a sign either of dysfunction or disease of the periodontal structures. Not all teeth with chronic periodontitis exhibit clinically perceptible mobility nor does hypermobility necessarily indicate trauma from occlusion. However, it is generally agreed that in advanced bone loss, the association of bone loss and tooth mobility is greater.

### Periotest S-

Periotest S, a mobilometer is an objective, dynamic measuring procedure, for evaluating damping characteristics of teeth stated that biophysical property of the periodontal ligament was more important in increased tooth mobility. The Periotest method evaluates periodontal behavior to a defined percussive force applied by a tapping device. The Periotest S has a head of 8 g and hits the tooth 16 times in four seconds. The amount of deflection is indicated by PTV. It is necessary to evaluate the loss of periodontal support in clinical terms by using clinical attachment level measurements. This mobility meter device evaluates the overall support of the periodontal structure rather than the support in the direction of the percussive movement.

It is very well accepted by the patients, due to its non-invasive and simple design. Andresen et al.used the instrument to assess tooth mobility in children and found that the device was well-accepted by children too.

## INVESTIGATING GADGETS IN ENDODONTICS

One of the most important stages in diagnosis and management of endodontic problems is radiographic examination. The periapical radiograph is widely used in the field of endodontics to detect the presence, location and size of periapical lesions. It also reveals information about root canal anatomy and proximity of neighbouring anatomical structures. In most endodontic cases, the periapical radiograph is the image of choice as it provides a high definition image at a low dose.13

Radiography is essential to successful diagnosis of odontogenic and nonodontogenic pathosis, treatment of the pulp chamber and canals of the root of a compromised tooth via intra-coronal access, biomechanical instrumentation, final canal obturation, and assessment of healing.

Imaging serves at all stages in endodontics 14

1. Preoperative Assessment
2. Intraoperative
3. Postoperative

### a. Digital Radiography-

Digital radiography has been available since the late 1980s and has recently been refined with better hardware and more user-friendly software. It has the ability to capture, view, magnify, enhance, and store radiographic images in an easily reproducible format that does not degrade over time.



### Fig:9 RVG 5200(Carestream Dental)

Digital radiography uses no x-ray film and requires no chemical processing. Instead, a sensor is used to capture the image created by the radiation source. This sensor is either directly or wirelessly attached to a local computer, which interprets this signal and, using specialized software, translates the signal into a two-dimensional digital image that can be displayed, enhanced, and analysed. The image is stored in the patient‟s file, typically in a dedicated network server, and can be recalled as needed.14

The distinction between computed and digital radiography is somewhat artificial, because both are digital technologies employing computers for their implementation. DR itself is divided into two main classes: indirect DR and direct DR (often referred to as DDR).

The most common DR detectors are based on amorphous silicon thin-film transistor (TFT) arrays, the dimensions of the array being the size of the area to be imaged. A transistor is a device that amplifies an electrical signal, and in the TFT array the amplified signal is stored as an electrical charge. The charge can be released by applying a high potential. In the TFT array, which is essentially a large integrated circuit, each row of detectors is connected to the activating potential and each column to a charge-measuring device. The potential is applied row by row, so that the timing of the detected signal determines the position of the pixel from which it originated. In a TFT array, there are as many transistors as there are pixels, and the size of each transistor, or pixel, is in the range 100–200 µm. The electronics and detectors are deposited in several layers on a glass substrate.

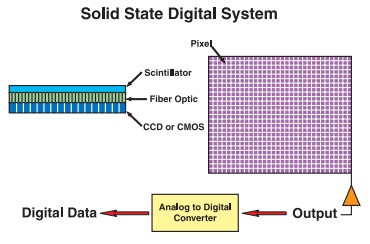
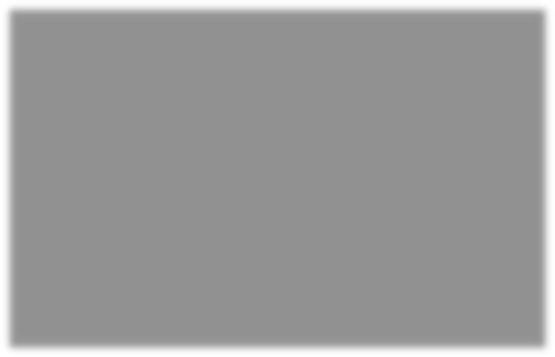
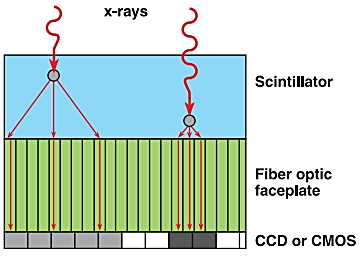
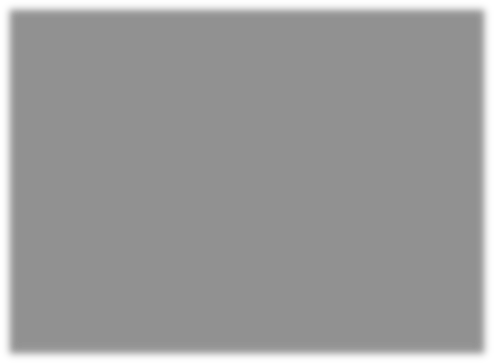


### Fig.10 The structure of a flat plate detector used for indirect digital radiography. a-Si, amorphous silicon.

Deposited above the charge collection device on the plate is an X-ray or light detector. The two major technologies presently used in intraoral digital X-ray systems are as follows:

### Solid-state detectors

* 1. Charge-coupled device (CCD)
  2. Complementary metal oxide semiconductor (CMOS), or a PSP (also sometimes referred to as an indirect acquisition modality)



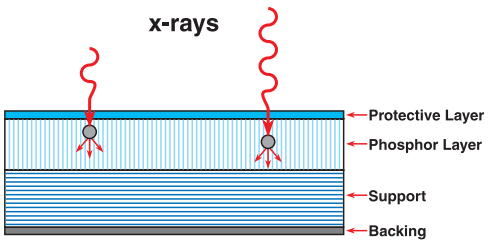
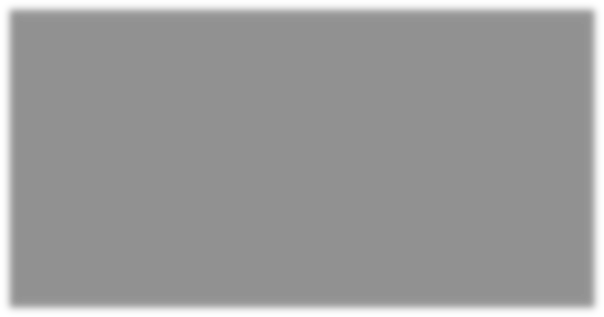
### Fig 11 Indirect solid-state X-ray sensors using a scintillator to convert X-rays to light photons. The image represents a small section of such a sensor. Solid-state sensor process. With the charge-coupled device (CCD), the pixel wells are read out in sequence, whereas with the complementary metal oxide semiconductor (CMOS), each pixel can be read independently

Solid-state detectors (CCD and CMOS) can be indirect detectors using a scintillating screen such as cesium iodide or gadolinium oxysulfide, or (less commonly) can use direct conversion of X-ray photons to electrons (e.g., Cadmium-Telluride technology).

### Storage phosphor detectors

1. Photostimulable phosphor (PSP)-

The intraoral photostimulable phosphor (PSP) is composed of a phosphor layer, a thin protective layer, support, and backing. X-ray energy is stored during exposure and subsequently released as photoluminescence on application of energy from a scanning laser. The emitted light is photo- multiplied and then converted to an electronic signal that is digitized.



**Fig12 A small section of PSP during exposure only**



### Fig. 13 Example of a PSP laser scanner (Scan-X; Air Techniques, NY). Detail shows loading area for the individual PSPs. Scanners come in a variety of sizes and configurations from the various vendors

**Working Principles of Digital Systems- Charge-Coupled Device-**

The earlier generation sensors had a smaller active area and limited x-ray absorption and conversion efficiency, in addition to being bulky. Sensors use an array of radiation-sensitive elements that generate electric charges proportionate to the amount of incident radiation. To reduce the amount of

radiation needed to capture an image, a light sensitive array was developed that uses a scintillation layer laid on top of the CCD chip or added with a fibreoptic coupling.

The CCD is composed of an electronic circuit embedded in several thin layers of silicon. The silicon chip usually is composed of an array of light sensitive pixels (picture elements), and each pixel consists of a small electron well into which the X-ray or light energy is deposited upon exposure. Each silicon atom in the detector chip is covalent with another silicon atom. When light photons strike the silicon and the energy exceeds the strength of the covalent bond, an electron hole pair is formed. Alternatively, electrons can be produced by a coating layer when direct technology is used instead of a scintillator layer. Either way, an electric charge is established by release of electrons. The electric charge in each „„pixel‟‟ well is proportional to the incident X-ray or photon energy.

Charge-coupling is a process by which the electrons from one well are transferred to another in a sequential manner, and this transfer concept has been compared to a „„bucket brigade.‟‟ The charge of each pixel is converted from an analogue electric signal representing the energy absorbed by the solid-state chip to a digital signal representing the discrete numeric pixel values for image display on a computer monitor.

### Complementary Metal Oxide Semiconductor Active Pixel Technology (CMOS-APS)

CMOS-based sensors, have an active transistor at each element location. The area available for signal generation is relatively less, and there is a fixed pattern noise. These sensors are less expensive to manufacture and have been shown to be equally useful for specific diagnostic tasks. Unlike the CCD, the CMOS chip requires very little electrical energy; therefore, no external power supply is needed to support USB utilization, and wireless applications are feasible. Wireless sensors are available-



### Fig 14 A and B, High-resolution complementary metal oxide semiconductor (CMOS) sensors are available from many manufacturers. Figure B shows wireless CMOS sensors transmit images to the chairside workstation by 2.4 GHz radio frequency.

It uses an active pixel technology, that is, each CMOS-APS has an active transistor built into each pixel and provides a reduction by a factor of up to

100 in the system power (translating into electric voltage) required when compared with CCDs. This has permitted the introduction of wireless radio frequency (RF) transmission of the acquired image.

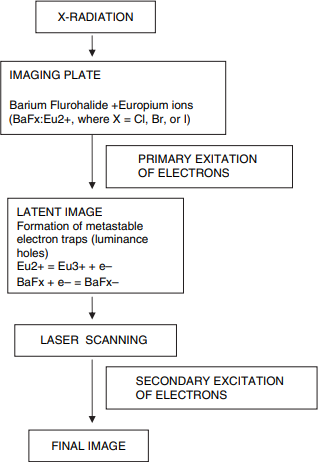
APS system eliminates the need for charge transfer between adjacent pixel wells extending the exposure latitude by suppressing „„pixel blooming.

Radiofrequency interference may be a problem with these sensors

### STORAGE PHOSPHOR DETECTORS

**Photostimulable Phosphor (PSP)-**

PSP technology is also referred to as computed radiography (CR). The PSP sensors are wireless. The PSP imaging plate works on the principle of radiation-induced emission of photo stimulated luminance.



**Flow diagram to demonstrate the sequence involved in the formation of a photostimulable phosphor (PSP) image.**

The phosphor is activated by a process called doping, which enables charges to be generated and stored when exposed to radiation. PSPs generally contain barium fluorohalide crystals with small amounts of bivalent europium atoms as an activator. When a storage phosphor imaging plate is exposed to X-radiation, the europium atoms in the phosphor crystalline lattice are ionized liberating a valence electron. This results in the formation of electron vacancy. The valence electrons are exited to the level of conduction band where they travel freely until trapped by so-called Farbzentren centres present in halide crystals to form metastable electrons with an energy level slightly lower than the conduction band but greater than that of the valence bond. These trapped metastable electrons constitute the latent image and their number is proportional to the number of incident X-rays. When the latent image is exposed to the red light of solid-state laser, the metastable electrons are again exited to reach high-energy conduction band where they recombine with Eu3+ atoms and return to low-energy valence bond (Eu3+ + e– = Eu2+). This results in the liberation of energy, emitted as blue light. The light is registered by a photo multiplier tube and converted into an analog electric output signal that is digitized, resulting in a digital image. Each pixel has a

numeric value that is proportional to the amount to light emitted from the corresponding area of the PSP imaging plate.

PSP plates can be damaged easily by scratching, but they are not as expensive as CCD or CMOS sensors. Incomplete erasure of the image can lead to ghost images when the plate is reused, and delayed processing can result in a decrease in image clarity. PSP-based sensors are used in high- volume scenarios. Spatial resolution is lower with this type of sensor, but it has a wider dynamic range. These sensors can tolerate a wider range of exposures to produce a diagnostically useful image

### Advantages of Digital X-ray Imaging4

* Significant advantages of digital radiographs over conventional radiographs include lower radiation doses, instant viewing, convenient manipulation, simple duplication; and easy archiving, elimination of variables associated with wet processing of conventional film; ease of transmission and of archiving and retrieving images from databases or picture archiving and communication systems (PACS); facilitation of use of an all-electronic patient record.

### Disadvantages-

* + The diagnostic quality of this expensive technology has been shown to be comparable to, but not necessarily superior to, perfectly exposed and perfectly processed conventional film-based radiography.
  + Interpretation of a digital radiograph can be subjective, similar to that of the conventional film.

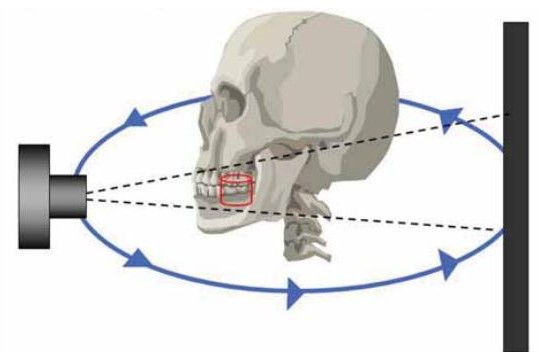
### Cone Beam Computed Tomography-

Cone beam computed tomography (CBCT) or digital volume tomography (DVT) is an extra-oral imaging system which can produce 3-dimensional scans of the maxillofacial skeleton.



### Fig:15 Planmeca ProMax 3D

CBCT is accomplished by using a rotating gantry to which an Xray source and detector are fixed. A divergent pyramidal- or cone-shaped source of ionizing radiation is directed through the middle of the area of interest onto an area X- ray detector on the opposite side of the patient. The X-ray source and detector rotate around a fixed fulcrum within the region of interest (ROI). During the exposure sequence hundreds of planar projection images are acquired of the field of view (FOV) in an arc of at least 180◦. In this single rotation, CBCT provides precise, essentially immediate and accurate 3D radiographic images. As CBCT exposure incorporates the entire FOV, only one rotational sequence of the gantry is necessary to acquire enough data for image reconstruction. CBCT is a complementary modality for specific applications rather than a replacement for 2D imaging modalities. 14



### Fig:16 The X-ray source and detector rotate once around the patient’s head. This results in a cylindrical volume of data being captured.

**Sophisticated software reconstructs the data, which may then be displayed in axial, sagittal and coronal planes.**

### Classification of CBCT 15

They are most commonly classified according to the dimensions of their FOV or scan volume. The following categorization has been proposed : Small volume (also referred to as focused, small field, limited field or limited volume) systems have a maximum scan volume height of 5 cm. Single arch CBCT scans have a FOV height of 5-7 cm within one arch; inter-arch CBCT scans have a FOV with a height of 7-10 cm; maxillofacial CBCT scans have a FOV height ranging from 10-15 cm; and craniofacial CBCT have a FOV height in excess of 15 cm.

### Imaging Tasks Improved Or Simplified By CBCT-

For endodontic treatment and assessments, there are at least five primary imaging tasks in which CBCT scans have a distinct advantage over traditional 2D radiographs. These tasks include evaluation of the following factors:

### Differential diagnosis

* 1. Lesions of endodontic origin
  2. Lesions of nonendodontic origin
  3. Diagnosis of endodontic treatment failures
  4. Vertical root fractures

### Evaluation of anatomy and complex morphology

* 1. Anomalies
  2. Root canal system morphology

### Intraoperative or postoperative assessment of endodontic treatment complications

* 1. Overextended root canal obturation material
  2. Separated endodontic instruments
  3. Calcified canal identification
  4. Localization of perforation

### Dentoalveolar trauma

1. **Internal and external root resorption**

### Presurgical case planning

1. **Dental implant case planning**

### Assessment of endodontic treatment outcomes

**Advantages of CBCT in Endodontics**

* It demonstrates anatomic features in 3D that intraoral, panoramic, and cephalometric images cannot.
* Because reconstruction of CBCT data is performed natively using a personal computer, data can be reoriented in their true spatial relationships
* Due to the isotropic nature of the constructed volume elements (“voxels”) constituting the volumetric dataset, image data can be sectioned non-orthogonally.
* Enhancements including zoom magnification, window/level adjustments, and text or arrow annotation can be applied.
* Cursor-driven measurement algorithms provide the clinician with an interactive capability for real-time dimensional assessment. On-screen measurements are free from distortion and magnification. 14,15

### Limitations of CBCT in Endodontics14

* Despite the provision of the third dimension, the spatial resolution of CBCT images is inferior to conventional film-based or digital intraoral radiography.
* It is susceptible to artifacts that affect image fidelity. Artifacts can be attributed to four sources:

1. the patient; (2) the scanner; (3) artifacts specific to the CBCT system used including partial volume averaging, under-sampling, and the cone beam effect; and (4) X-ray beam artifacts arising from the inherent polychromatic

nature of the projection Xray beam that results in what is known as beam hardening .

Beam hardening results in two types of artifact:

* 1. distortion of metallic structures due to differential absorption, known as a cupping artifact
  2. streaks and dark bands that can appear between two dense objects. The presence of dental restorations, including apically positioned retrograde restorations, in the FOV can lead to severe streaking artifacts

### Endodontic Software ‘TDO’

TDO Software was introduced commercially in early 2000 revolutionizing the field of endodontic record keeping.

### Features and benefits-

Absolutely No Paper Records

All clinical charting, scheduling, financials and reports are done in TDO Software. Even patient registration and health history is completely digital with the TDO Info-grabber.

Contemporaneous Data Collection

It does not require re-entering the same data into multiple forms. As it is designed according to operatory workflow, TDO makes it possible to record complicated and sophisticated data as we are working.

Digital Radiography Integration

Unlike other programs, TDO Software integrates with the following digital radiography devices: Dexis, Schick, Sirona, Trophy/Kodak, Digora for Windows (OpTime), Gendex, ScanX, E2V and any other digital radiography manufacturer that provides a TWAIN driver.

Unequalled Imaging Engine

The Organizer has built-in photo-editor, email and presentation capabilities all in one. All programs are seamlessly integrated and don‟t require any other external imaging program or design tools. So, there is no need to buy expensive external applications.

Digital Imaging

TDO Software supports all major digital imaging technologies, including Conebeam CT Imaging, Digital Radiography, Digital Photography, Hi- Definition Video Capture and Dental Microscopy.

## PAIN CONTROL

### Local Anaesthesia for Endodontics

Effective local anaesthesia is the bedrock of pain control in endodontics and restorative dentistry. Regardless of the clinician’s skills, both treatment and patient management are difficult or impossible to deliver without effective pain control.

### Mechanisms of Action for Anaesthetics16

Local anaesthetics block sodium channels by partitioning into two types-

* + 1. Uncharged basic form of the molecule (RN), which crosses cell membranes
    2. Charged acid form of the molecule (RNH+), which binds to the inner pore of the sodium channel.

However, molecular research has demonstrated the existence of at least nine subtypes of voltage-gated sodium channels (VGSCs) that differ in their expression pattern, biophysical properties, and roles in mediating peripheral pain.

### Table.1 Voltage-Gated Sodium channels and Pain

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Channel**  **Subtype** | | **Tissue**  **Expression** | | **Tetrodotoxin** | **Peripheral Role**  **in Pain** |
| NaV | 1.1 | Central Nervous System (CNS),  Sensory neurons | | Yes | ? |
| NaV 1.2 | | CNS | | Yes | No |
| NaV | 1.3 | CNS | | Yes | No |
| NaV | 1.4 | Muscle | | Yes | No |
| NaV | 1.5 | Heart | | Somewhat | No |
| NaV | 1.6 | CNS,  neurons | sensory | Yes | ? |
| NaV | 1.7 | CNS,  neurons | sensory | Yes | ? |
| NaV | 1.8 | Sensory neurons | | No | Yes |
| NaV | 1.9 | Sensory neurons | | No | Yes |

The broad class of VGSCs can be divided into-

* channels that are blocked by a toxin (tetrodotoxin [TTX])
* channels that are resistant to the toxin (TTX-R)

Most TTX-R channels are found primarily on nociceptors. These channels also are relatively resistant to local anesthetics and are sensitized by prostaglandins. The presence of TTX-R sodium channels may explain why local anesthetics are less effective when administered to patients with odontalgia.

Local anesthetics have other mechanisms that may contribute to their pharmacology for treating odontogenic pain. It modulates certain G protein– coupled receptors (GPCRs). The GPCRs are a major class of cell membrane receptors, and many classes of dental drugs (e.g., opioids, catecholamines) and endogenous mediators produce their effects by activating specific GPCRs and their related second messenger pathways. Studies suggest that local anesthetics inhibit the G-alpha-q (Gαq) class of GPCRs, which includes receptors activated by inflammatory mediators such as bradykinin. Local anesthetics may therefore block the actions of a major hyperalgesic agent.

### Clinically Available Local Anaesthetics

**Table 2. Local anaesthetics available in United States**

|  |  |
| --- | --- |
| **Anaesthetic** | **Vasoconstrictor** |
| 2% Lidocaine | 1:100,000 epinephrine |
| 2% Lidocaine | 1:50,000 epinephrine |
| 2% Lidocaine | Plain |
| 2% Mepivacaine | 1:20,000 levonordefrin |
| 3% Mepivacaine | Plain |
| 4% Prilocaine | 1:20,000 epinephrine |
| 4% Prilocaine | Plain |
| 0.5% Bupivacaine | 1:200,00 epinephrine |
| 4% Articaine | 1:100,000 epinephrine |
| 4% Articaine | 1:200,000 epinephrine |

### Important Clinical Factors 16

1. Traditional Methods of Confirming Anesthesia-

It involves questioning the patient (―Is your lip numb?‖), soft tissue testing (e.g., lack of mucosal responsiveness to a sharp explorer), or simply beginning treatment. However, these approaches may not be effective for determining pulpal anesthesia.

1. Determining Pulpal Anesthesia in Asymptomatic Vital Teeth –

Anesthesia can be measured more objectively by applying a cold refrigerant or by using an electrical pulp tester (EPT).

1. Determining Pulpal Anesthesia in Symptomatic Vital Teeth-

After administration of a local anesthetic, testing with a cold refrigerant or an electrical pulp tester can be used to evaluate pulpal anesthesia before an endodontic procedure is started.f the patient responds to the stimulus, pulpal anesthesia has not been obtained, and supplemental anesthetic should be administered. However, in patients presenting for an emergency appointment with a painful vital tooth (e.g., symptomatic irreversible pulpitis), the lack of a response to pulp testing may not guarantee pulpal anesthesia. Therefore, if a patient experiences pain when the endodontic procedure is started, supplemental anesthetic is indicated, regardless of the responsiveness to pulpal testing.

1. Patient Who Has Had Previous Difficulty with Anesthesia-

Anesthesia is more likely to be unsuccessful in patients who report a history of previous difficulty with anesthesia. In such patients, supplemental injections should be considered.

### SUPPLEMENTAL ANESTHESIA

**Manual Devices-**

### a. Intraosseous Anesthesia (IO)-

The thickness of the cortical plate of posterior mandibular region condemns the use of infiltration injections. The intraosseous injection overcomes this problem by allowing direct access to the cancellous bone via perforation of the cortical bone.

When a primary IO injection was compared with an infiltration injection, the IO technique showed a quicker onset and a shorter duration of anesthesia.17

### 1. The Stabident IO system (Fairfax Dental Inc., Miami, Florida)16,17,18

It is composed of a slow-speed, handpiece-driven perforator and a solid 27- gauge wire with a beveled end that drills a small hole through the cortical plate .



### Fig:17 Stabident perforator, a solid 27-gauge wire with a bevelled end Steps-

1. After attaching the plastic base to a latch-type slow-speed contra-angle hand piece, the operator anesthetizes the gingiva with the ultra- short needle and an amide anesthetic with vasoconstrictor, and then drills a small hole into the alveolar bone using the perforator (Figure 1)



### Fig:17a Stabident perforation of bone

1. Remove the perforator and then use light pressure upon inserting the injection needle into the hole and inject slowly for enhanced patient comfort.



### Fig:17 (b) Stabident® needle injection.

**Features-**

The system saves valuable time as there is no delay between injection and effect. Work on the tooth can commence in less than 30 seconds after the injection.

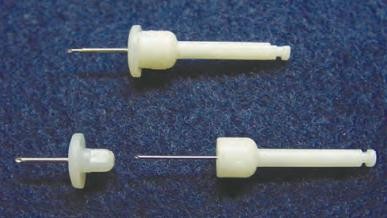
### Limitations-

To locate the perforated hole for injection needle insertion

### 2.X-Tip® (Dentsply International Inc., Tulsa, OK, USA)

1. Tip® was designed to solve the problem created by the Stabident® system of having to locate the perforated hole for injection needle insertion.

Components of X-Tip® consist of a 27-gauge perforator drill, a 25-gauge guide sleeve that fits over the drill, and a 27-gauge ultra-short needle.19



### Fig:18 The X-Tip anesthetic delivery system consists of an X-tip (top) that separates into two parts: the drill (a special hollow needle) and the guide sleeve component (bottom)

**Steps16**

* 1. Once the drill leads the guide sleeve into the cancellous bone, it is removed and the guide sleeve left in place (through which the needle is directed into the cancellous bone



### Fig:18 a Anaesthetic solution is injected through the X-tip guide sleeve. Advantages-

It has a definite clinical advantage over the Stabident system because the X- Tip perforation may be made at an apical location in unattached gingiva. If the Stabident system is used apically in alveolar mucosa, the hole created for delivering the anesthetic solution is almost impossible to find. 18

### When to use 16,18

The clinician may want to consider using the X-Tip system in an apical location in specific clinical situations to achieve inta-pulpal anesthesia-

* + 1. when periodontal pocketing does not allow perforation into cancellous bone through the more coronal attached gingiva or when interproximal space is lacking (i.e., roots are too close together).
    2. If the Stabident system fails, then use X-Tip apically to achieve pulpal anesthesia.

### IntraFlow® (Pro-Dex Incorporated, Santa Ana, CA, USA)

Equipped with a hand piece, 24-gauge hollow perforator, and disposable transfuser, IntraFlow® allows the operator to perforate the bone and deposit

the solution all in one step, after the attached gingiva and the periosteum have been anesthetized with local anesthesia.



### Fig: 19 IntraFlow® (Pro-Dex Incorporated, Santa Ana, CA, USA)

It utilizes low speed, high torque, and steady pressure to penetrate the bone and deliver the solution. Once the perforator penetrates the bone, the transfuser directs solution from the cartridge to the perforator for infusion.18



### Fig:19 (a) IntraFlow Perforation and Injection

* **Success of intraosseous injections** –

Success of these supplemental intraosseous injections in achieving pulpal anesthesia in patients with irreversible pulpitis has been reported to be 82- 98%.

Supplemental IO injections of lidocaine and mepivacaine with vasoconstrictors allow quick onset and increase the success of the inferior alveolar nerve block for approximately 60 minutes.

Using 3% mepivacaine plain results in pulpal anesthesia for approximately 30 minutes

### Failure -

* 1. If the anesthetic solution flows out of the perforation site (backflow), anesthetization will not occur. R-eperforation or use of another perforation site is a practical way to gain access to the cancellous bone in such cases.
  2. In fewer than 10% of cases, constricted cancellous spaces may limit the distribution of the anesthetic solution around the apices of the teeth. In such cases, failure may result even if the anesthetic solution is delivered intraosseously.

### Perforator Breakage-

1. In 1% of cases, the metal perforator separates from the plastic shank during use. The metal wire is easily removed with a hemostat. This separation usually occurs during a difficult perforation (e.g., dense cortical bone); the wire probably is heated excessively, causing the plastic hub to melt.
2. No perforator breakage (metal perforator breaking into parts) has been reported in numerous controlled clinical studies. However, excessive torquing of the perforator laterally by an inexperienced operator may result in breakage.

### Optimal Location for Injection Site-

Injection at a site distal to the tooth to be anesthetized produces the best anesthesia.

Maxillary and mandibular second molars are an exception to this rule. A mesial site should be selected for these teeth.

### Onset of Anesthesia-

It is immediate, which eliminates the waiting period.

### Duration-

With a primary IO injection, the duration of pulpal anesthesia declines steadily over an hour.

With a supplemental IO injection of lidocaine after the inferior alveolar nerve block in patients without pain, the duration of pulpal anesthesia is very good for an hour.

In patients with irreversible pulpitis, supplemental IO injection using either the Stabident or X-Tip system provided anesthesia for the entire débridement appointment

### Systemic Effects-

1. **Clinical Significance of Increased Heart Rate**-

Although the patient is likely to notice the transient tachycardia that occurs after Stabident or X-Tip IO injection of 2% lidocaine with 1:100,000 epinephrine, it generally is not clinically significant in healthy patients.

### Postoperative Discomfort-

Less postoperative discomfort is reported for the Stabident IO injection than for IL injection.

One study found that significantly more men experienced postoperative pain with the X-Tip system than with the Stabident system. This might be being due to the denser, more mineralized bone in the posterior mandible in men and to the fact that the diameter of the X-Tip perforating system is larger than that of the Stabident perforator, meaning the X-Tip system generates more frictional heat during perforation.16

### Medical Contraindications-

Patients taking antidepressants, nonselective beta-blocking agents, medicine for Parkinson disease, and cocaine should not receive IO injections of solutions containing epinephrin. 3%mepivacaine plain is preferred.

### Intraligamentary Injection Devices-

The IL injection is another technique that is used if a conventional injection is unsuccessful.

### Success-

For use as a primary injection, IL injections have a reported success rate of about 75% in mandibular and maxillary posterior teeth, with a duration of pulpal anesthesia of 10 to 15 minutes. Success rates are low in anterior teeth.

For use as a supplemental injection (standard techniques have failed to provide adequate anesthesia), good success rates are achieved, but the duration of pulpal anesthesia is approximately 23 minutes.

### Mechanism of Action

An IL injection forces anesthetic solutions through the cribriform plate into the marrow spaces around the tooth. The primary route is not via the periodontal ligament,the mechanism of action is not a pressure anesthesia. The IL injection should be considered an intraosseous injection.

### Back-Pressure

Studies have shown that the most important factor for anesthetic success with an IL injection is injection under strong back-pressure. Pressure is necessary to force the solution into the marrow spaces.

### Amount of Solution Delivered

Usually about 0.2 ml of solution is deposited with each mesial and distal injection, using a traditional or pressure syringe.

### Onset of Anesthesia

It is immediate with an IL injection. If anesthesia is still not adequate, reinjection is necessary.

### Contraindications-

It is a hazardous method for patients with the risk of Endocarditis or immunosuppressed patients. Moreover, in case of a profound marginal periodontitis or in teeth with a sclerotic periodontal gap, the usefulness of ILA is reduced and alternative anesthetic techniques (IANB, IA) are recommended.

Various injection devices are available, both as manual instrument (as pistol- type, penholder grip syringe or dosing wheel syringe) as well as computer- controlled systems (CCLADS: computer controlled local anesthetic delivery system

### Manual Instruments-

* + 1. **Peri-Press and Ligmaject-**

In the late 1970’s two new local anesthetic devices-the Peri-Press and the Ligmaject were introduced in the United States.

The small needle is inserted into the mesial gingival sulcus and in contact with the tooth. The needle is supported by fingers and positioned with maximal penetration between the root and crestal alveolar bone. Pressure is slowly applied to the syringe handle for 20–30 seconds. Backpressure has to be developed for this technique to work and blanching of the soft tissues would be a sign of probable success. If analgesic solution flows readily out of the sulcus then analgesia will not be achieved. Pressure is necessary to force the solution into the marrow spaces to contact and block the dental nerves. The technique should be repeated on the distal and lingual surfaces of the involved tooth.



### Fig 20 a.Peripress for intraligamental injections b. Needle insertion for intraligamental injection

The Peri-Press syringe has a metal sleeve protecting the cartridge, while the Ligmaject has a Teflon sleeve covering its cartridge. Each ―squeeze‖ of the trigger of these devices deposits a fixed volume of anesthetic solution, (0.14 ml. for the Peri-Press, 0.2 ml. for the Ligmaject), which has proved to be an adequate volume for Grade A pulpal anesthesia.

The manufacturers of both syringes recommend the use of a 30-gauge short dental needle.

### Paroject (Septodent)-

Features & benefits

* + - * Designed for performing ―PDL‖ injections.
      * Designed to handle any standard dental cartridge and uses standard disposable dental needles.
      * Lightweight and compact design.
      * Click activator disperses a calibrated .06 ml dose.

### Fig 21 Paroject Intraligamental Syringe

**2. SOPIRA Citoject syringe (Kulzer, Mitushi Chemical Groups)-**

Available in stainless steel or light alloy. Features-

* Balanced weight distribution for stable handling and precision
* The integrated plastic sleeve offers added safety
* The stainless-steel models can be thoroughly cleaned and sterilised
* Unparalleled control for injection: 0.06 ml of anaesthetic at the press of the lever.



### Fig 22 SOPIRA Citoject syringe

Available in stainless steel or light alloy, with straight or angled headpiece, and for 1.8 ml or 2.2 ml glass cartridges.

### Computer-Controlled Injection devices

In 1853, Pravex invented the syringe. Almost 150 years later, there have been few changes to the original design. In the early 1920s, Cook Laboratories added the ability for the syringe to accept a local anaesthetic cartridge and in the mid 1950 s; the syringe was given the ability to aspirate. Over the past six years, the design of the syringe and the mode of local anaesthetic delivery has suddenly changed drastically with the advent of computer -controlled injection devices. 20

**Advantages of computer-controlled injections**:

* Possible decrease in pain during the injection.
* Less effusion of local anaesthetic to areas away from the desired injection location due a slower injection rate. Some proponents of computer-controlled injections theorize that this may result in more profound local anaesthesia and less post-operative pain.
* The ability to do periodontal ligament injections without the worry of the increased pressure that is required to push the solution into the PDL space.20

**Disadvantages of computer-controlled injections**:

* Set up, breakdown and disinfecting time. Because the injections are given slowly, the needle will remain in the tissue for a longer time. Anxious patients may have difficulty with this.
* Increased cost.20

### QuickSleeper® (Dental HiTec, Cholet, France):

This machine was invented in France by Dr. Alain Villette in 1991.

It is the only local anaesthetic delivery device that allows the ability to perform all intraoral local anaesthetic injection techniques (IO injection, intraseptal, intraligamentary, and infiltration).

The extra feature that gives the Quicksleeper this ability is a built-in motor in the syringe/handpiece that renders the syringe both an injector and a perforator of bone. That is, it’s handpiece has the ability to perform an intraosseous injection via a motor driven perforation of the cortical plate of bone. A standard dental needle that attaches to the syringe spins as the motor rotates the handpiece thus acting as a perforator.



### Fig:23 QuickSleeper® (Dental HiTec, Cholet, France)

It is controlled by a double foot pedal. One pedal activates the rotation of the handpiece and this pedal is depressed if the operator wants to perform an intraosseous injection. The second pedal initiates the injection of the local anaesthetic. If a standard technique such as a block or infiltration is being used, only the injection pedal is pressed.

The amount of anaesthetic desired is pre-chosen by pressing a button on the counter-top base of the machine. The operator can choose volumes of 1/4, 1/2, 3/4, or a full cartridge. Once the injection is initiated, it begins injecting

slowly and the injection speed gradually accelerates. This once again takes advantage of the initial slow injection being less painful. This initial slow speed can be bypassed by a double press of the foot pedal.19,20

### It works in 3 phases:

1. In phase 1 the mucosa with the special DHT needle is pre-extinguished (the perioste is not touched, but it is delivered). The special shape of the needle in combination with the computer-controlled delivery rate of anesthesia ensures that the patient experiences no pain.
2. In phase 2 the same needle drills slowly and in a controlled manner in the bone. There is no feeling in the bone, so the patient feels no pain.



### Fig: 23 a system drills in the bone

1. During phase 3, the anesthetic fluid is injected into the spongy bone. It spreads in the spongy bone and adjacent tissues. The needle is withdrawn and the treatment can start immediately

### QuickSleeper S4-

It is 40% lighter and 19% reduced in diameter, compared to the previous model.

New and improved features include-

* 1. wireless and battery-less pedal
  2. automatic and continuous injection system to limit needle obstruction
  3. high performance ball bearing system that reduces vibration during needle rotation and increases user comfort.

The device requires specially developed needles (perforation and injection are managed with the same needle).



### Fig:23 b QuickeSleeper S4

**Benefits-**

1. Maximum Precision
2. It is handled like a pen which enables anaesthesia to be precise and comfortable.
3. It is compatible with standard dental needles.
4. There are no disposable components and therefore there is no ongoing cost.
5. There is an initial slow speed that automatically accelerates for a possible less painful injection.

### Disadvantages:

* 1. Handpiece is relatively heavy weighing 240 g. as compared to a standard syringe that weighs 80 g. This weight may be difficult for a small-handed dentist to control.
  2. Most expensive of the three devices.
  3. The operator cannot control when the injection speed increases.

### SleeperOne® (Dental HiTec, Cholet, France):

Similar in design to the QuickSleeper® system, it also features a pen grip hand piece, a control unit, a foot pedal, PAR system, and 4-injection speeds.



### Fig:24 a.SleeperOne kit (Dental HiTec, Cholet, France):

What distinguishes the two systems however, is that SleeperOne does not feature a rotating needle and therefore excludes transcortical and osteo- central use.



**Fig:24 b SleeperOne handpiece**

Highly efficient for PDL injections, it may also be used for intraseptal (ideally in pediatric patients), infiltration, nerve block, and palatal infiltration anesthesia.18



### Fig:24 c Intraligamentary injection with SleeperOne

1. **Wand/CompuDent® (Milestone Scientific, Inc. Livingston,NJ):**

In the mid-1990s, Milestone Scientific Inc. released the first computer- controlled delivery system into the North American marketplace. The Wand met with great excitement in the dental profession and initial purchases were so brisk that dentists found themselves on a waiting list in order to purchase a machine.

However, because of a few glitches, the popularity of The Wand died down but to their credit, Milestone addressed the difficulties that dentists were encountering. As a result, they have improved their product, now called The Wand Plus.16



### Fig:25 Compudent/Wand (Milestone Scientific, Inc. Livingston,NJ): The Wand Plus

It has three components-

1. a table-top base unit
2. a foot pedal
3. a handpiece.

The base unit is called a microprocessor and this is where the foot pedal and the local anaesthetic cartridge are attached. The microprocessor is a drive unit that recognizes signals from the foot pedal and as a result, it delivers the local anaesthetic by advancing a plunger into the anaesthetic cartridge. The local anaesthetic is pushed into a disposable tubing system and this connects to the handpiece and needle. Because the local anaesthetic cartridge is on

the table-top machine and not in the handpiece, a standard dental needle cannot be used. There is no need for the cartridge perforating end of the needle and thus, a luer- lock needle is required.

The system has 2 possible rates of local anaesthetic delivery both controlled from the foot pedal. The slow speed allows for a cartridge to be dispensed in four minutes and the fast speed will dispense a cartridge in about one minute.16,20

### Steps involved-

1. Injections should begin with the slow speed to initially anaesthetize the tissues as painlessly as possible.
2. When the tissues are properly anaesthetized, the pedal is depressed again and the machine will change to the fast speed of injection. It is also suggested that only the slow speed be used for PDL and palatal injections. Aspiration is also controlled from the foot pedal or it can be controlled from the base unit.

The tubing and the handpiece are disposable items to be used one per patient

**Advantages**-

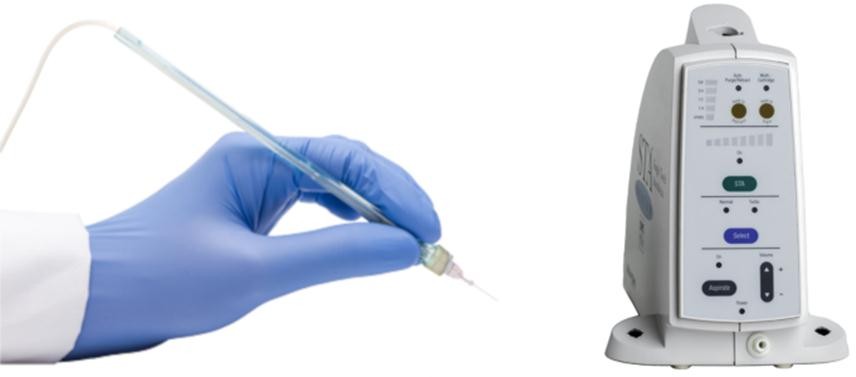
* Comfortable, light and easy to maneuver handpiece.
* No vibration in the handpiece since it does not have a motor or electrical component in it.
* A two-speed system with an initial slow speed for a less painful injection. The operator has the ability to change speeds anytime during the injection.
* Because the local anaesthetic cartridge is not on the handpiece, the assistant can add another cartridge to the base unit while the needle remains in the patient’s mouth.

**Disadvantages**-

* Long aspiration cycle that takes approximately five seconds. This however is a vast improvement since the old Wand system had a 14-second aspiration cycle.
* The inability to use a full local anaesthetic cartridge. The tubing must initially be purged of air and this is done by running anaesthetic solution through the tubing. Some of the anaesthetic is lost in this process by being expressed out of the handpiece. As well, the tubing will never be completely emptied of anaesthetic. These two situations result in the loss of between 0.3-0.4 mls of local anaesthetic.
* There is ongoing maintenance required. The plunger on the base unit has an o-ring on it that is part of the aspiration system. This o-ring must be lubricated on a regular basis to maintain the reliability of the aspiration. The Wand Plus has an audible signal to remind the owner when to carry out this lubrication.
* It is not compatible with standard needles. It requires luer-lock needles.
* The design of this product is such that the local anaesthetic cartridge is not inside the handpiece but on the counter-top microprocessor. Therefore, it is not in the dentist’s line of sight during the injection. The dentist therefore would not know if this machine was actually injecting unless there was some signal to indicate that an injection was actually occurring. As a result, an audible beep has been programmed into the computer and this beep carries on throughout the course of the injection.20

### STA® (Single Tooth Anesthesia®-Milestone Scientific, Inc., Livingston, NJ):

With built-in CompuFlo® and Dynamic Pressure Sensing technology, it provides visual and audible feedback while continuously monitoring the pressure of the solution throughout the injection. Sensing needle-tip pressure, these features advise the user on ideal needle placement for PDL injection and prevent dangerously high-pressure flow during injection.



### Fig:26 STA System

It is the only anesthesia system that provides clinicians with the 3 critical elements of information when performing a STA-Intraligamentary Injection:

1. It guides the clinician to position the needle tip to the periodontal ligament.
2. It provides ongoing feedback that ensures the needle has not moved during the procedure.
3. It alerts the dentist if there is a needle blockage or any leakage in the system.

### Performing the STA-Intraligamentary Injection-

1. Turn the STA (Single Tooth Anesthesia) drive instrument to ―On‖.
2. Load and attach the Wand® STA bonded handpiece with the pre- attached bonded 30 gauge 1.27cm (30 gauge ½ inch) needle and the appropriate anesthetic. The instrument will automatically purge the air from the system. Rest the handpiece in the cap holder.
3. While holding the handpiece, place the needle into the gingival sulcus of the tooth to be anesthetized.
4. Simultaneously, activate the ControlFlo® rate by depressing the foot control. It is important to gently and slowly advance the needle within the sulcus. Use a finger rest to control and stabilize needle movements.
5. It provides a continuous audible and visual feedback to guide the needle tip to the periodontal ligament. As the foot control is depressed, the device will begin sensing. The user will then hear the word ―Cruise‖

at which time the cruise control function can be engaged by removing one’s foot from the pedal. If the operator’s foot is removed from the foot control within 4 seconds of hearing the spoken word ―Cruise‖ the instrument will engage cruise control.

1. DPS technology provides real time pressure feedback via: a. The visual Pressure Sensing Scale (Gauge) comprised of a series of orange, yellow and green LED lights. The orange LED’s indicate minimal pressure, the yellow LED indicate mild pressure and the green LED’s indicate moderate pressures indicative of the periodontal ligament tissue. One should always use a light, delicate grasp and apply a light, gentle force when positioning the needle into the sulcus and contacting the periodontal ligament.
2. When the periodontal ligament is identified, the user will hear the letters ―PDL‖ spoken, followed by a series of extended tones ―beeeep, beeeep‖ indicating correct needle positioning

### Drug Selection:

When using 2% Xylocaine Hydrochloride 1:100,000 Epinephrine or other local anesthetics formulated with a 2% concentration the following recommendations are made:

* + A drug volume of 0.9 ml is recommended for single rooted teeth.
  + A drug volume of 1.8 ml is recommended for multi-rooted teeth.

### Advantages-

1. DPS technology provides the user with important on-going information that the needle has not moved from the optimal location during the entire injection process.
2. It alerts the operator to the proper hand pressure applied to the handpiece. Excessive pressure can result in ―blockage‖ of flow of anesthetic solution

### Disadvantages-

1. Removal of the needle from the ligament should be performed mid-way during the aspiration cycle to prevent a back-spray of anesthetic

solution into patient’s mouth. Since the injection is performed under pressure, if the needle is otherwise removed, the patient’s mouth will be sprayed with bitter tasting anesthesia. Therefore, the operator is advised to remove the needle during aspiration, i.e. when the STA System is retracting during aspiration

1. **THE COMFORT CONTROL SYRINGE**

It was released in February 2001 by Dentsply — Midwest. In the early 1990s, Dr. Mark Smith, a dentist from London, ON, invented a device that he incorporated into his practice as the sole local anaesthetic delivery method. After perfecting the system, he released the rights of this device to Dentsply.



**Fig:27 Comfort control syringe system**

This system differs from the other two in that there are no foot pedals.

Instead, there are two components-

* 1. base unit that can be wall mounted or table-top
  2. syringe.

Many of the functions of the syringe can be controlled directly from computer during the injection process. The base unit allows the dentist to program one of five different injections by pressing a single button. 21

The five buttons marked on the base unit are-

1. block
2. infiltration
3. Intra-ligamentary
4. intraosseous
5. palatal

Each of these injections has a specific corresponding rate of local anaesthetic delivery associated with it. For example, the rate of injection for an infiltration (the fastest injection) is 0.017 ml/sec, which corresponds to the delivery of one cartridge in 80 seconds. This compares to the rate for the palatal injection (the slowest injection) that is set at 0.008 ml/sec, which allows for the delivery of one cartridge in 4 minutes. If at any point in the injection process the dentist decides that he wants to speed up the process, a double rate button can be pushed on the syringe and the injection will take half the amount of time.

Once the injection technique is decided upon, and the appropriate button has been pressed, the device is ready to inject. There are three buttons on the syringe that control the remainder of the injection process.

The first button is the start/stop button, the next button is the aspiration function and the last button is the double rate function. Once the start button is pressed, the injection begins at a pre-programmed, slow speed for 10 seconds. This will theoretically anaesthetize the tissues in as painless a manner as possible and once this 10 second phase has elapsed, the computer will automatically change speeds to the rate of injection previously chosen by the operator.

The base unit has three digital readouts that provide the dentist with feedback during the injection. These displays show the rate of injection (chosen by the operator), time elapsed during the injection, and the cumulative volume injected. The volume reading is important during injections such and the PDL injection where the dentist may wish to give a precise amount per root or simply for charting purposes.

There is a disposable component with the CCS. It is a clear plastic cartridge sheath that attaches the cartridge to the syringe. This cannot be sterilized and therefore one is used per patient.

**Advantages:**

1. A wide range of injection speeds, controlled by the operator.
2. An initial, extremely slow rate, 10 second injection to possibly decrease the pain associated with tissue expansion.
3. The ability to control the computer directly from the syringe thus eliminating the need for a foot pedal.
4. A digital readout showing the volume injected.
5. least expensive of the products.

**Disadvantages -**

1. A dentist with a very small hand may have difficulty negotiating the buttons due to the increased circumference of the syringe. The circumference of the CCS syringe is 112mm compared to 36mm for a traditional syringe, and 17mm for The Wand.
2. Because of the electronics in the syringe, the operator will feel a slight amount of vibration in the syringe while the injection occurs. This will not affect the anaesthesia but it certainly is a feeling that is different from the traditional syringe or The Wand which both have no such vibration. The vibration in the Quicksleeper is very minimal.
3. It takes some practice for the dentist to get used to maneuvering their fingers to press the buttons on the syringe.20

### CALAJECT™

The system controls the flow rate, which ensures a smooth and gentle flow of anaesthesia. Even palatal injections can be carried out with less discomfort for the patient.

It consists of –

* 1. touch panel
  2. dispensing handle with a stand
  3. foot control



### Fig:28 CALAJECT™

**Control unit**

* Touch screen - easy and simple to operate.
* Display of actual injection pressure - including automatic switch-off in case of excessive resistance in the tissue.
* Acoustic signal indicating actual flow rate.

### Handpiece and stand

* Vibration free and tactile hand piece.
* Visual contact with the cartridge during the entire injection.
* Automatic aspiration when pressure on the foot control is eased.
* Used with standard dental needles and cartridges.

### Advantages-

* The light pen grip provides a relaxed working position and good finger support shows where the needle can be kept perfectly still in situ.
* Runs on battery
* One instrument for all odontological local anaesthesia.

### C.PRIMEQUAL

Dose per Dose delivery - Metered Dosing Painless injection - Low pressure injection



### Fig;29 Primequal

No training required – Easy to use Safety - Single Use Locking System

*Not much information is provided using this system.*

### Vibrotactile Devices

It uses vibration to reduce the sensation of pain during injections. It takes advantage of the gate control theory of pain management.

### Mechanism-

It has been suggested that when vibration is applied as a counter stimulation to an anesthetic injection, it will reach the brain before the pain sensation does. The brain can perceive only one sensation at a time; therefore, the sensation that arrives at the brain first is the one that will be felt.

These devices have shown controversial performance.18

### VibraJect

It is a simple and cost-effective solution to alleviate injection discomfort. It works because the light pressure of a Vibraject injection is carried rapidly to the brain on thicker more insulated nerve tissues.



### Fig:30 VibraJect

While Nanitsos *et al* and Blair have recommended the use of VibraJect for painless injection, M Saijo *et el* , Roeber B *et el* and Yoshikawa F et el have found no significant pain reduction when VibraJect.

### Other devices availabe working on the same principle are Dentalvibe, Syringe Micro Vibrator (smv) and Accupal.-

Dentalvibe and syringe micro vibrator uses micro-vibration to the site where an injection is being administered while Accupal uses both vibration and pressure.

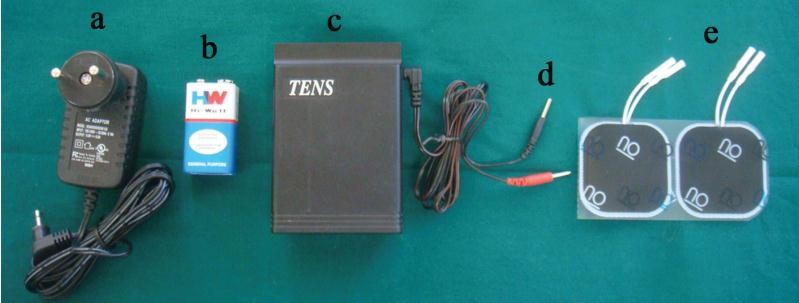
However, there are no good quality studies that have compared these devices with conventional syringes. So, their effectiveness is yet to be confirmed by independent sources.19

### Transcutaneous electric nerve stimulation (TENS) in dentistry 22

A non-pharmacological method for pain control is the use of transcutaneous electrical nerve stimulation [TENS]. FDA [Food and Drug Administration] has approved TENS as a method of pain alleviation and classified it as class II device in 1972.

### Mechanism-

During TENS therapy, pulsed electrical current is generated either by A.C. mains or using batteries [usually 9V] and delivered across the intact skin surface via electrodes to stimulate superficial nerves for localized pain relief. Low voltage electric current delivered through wire from a power unit to electrodes placed on the skin.



### Fig: 23 a) AC adapter b) 9V battery c) TENS unit d) Lead Wires e) Electrodes

TENS is commonly used by health professionals for acute and chronic pain management.

In dentistry, though TENS has potential applications, it is not used that frequently.

### Contraindications: -

* Patients with cardiac pacemakers
* Neurological disorders like epilepsy
* Pregnant patients
* Difficult to position the electrode intraorally

## VISUAL ENHANCEMENTS

First step that has to be performed is the isolation of the operative field with a dental dam, than under constant magnification and lighting we have to proceed with the opening of the pulp chamber with rotary instruments and ultrasonic tips.

### Dental operating microscope (DOM)

The use of the dental operating microscope (DOM), which is intended to provide superior magnification, increased lighting, and enhanced visibility, is recommended to determine the location of root canal orifices in the properly prepared coronal access.

### History-23

In 1981, Apotheker introduced the dental OM. The first OM was poorly configured and ergonomically difficult to use. It was capable of only 1 magnification, was positioned on a floor stand and poorly balanced, had only straight binoculars, and had a fixed focal length of 250 mm. This OM used angled illumination instead of confocal illumination. It did not gain wide acceptance, and the manufacturer ceased manufacturing it shortly after its introduction. Its market failure was more a function of its poor ergonomic design than its optical properties, which were actually good.

Selden was the **first endodontist** to publish an article on the use of the OM in endodontics. He discussed it‟s use in the conventional treatment of a tooth, not in surgical endodontics.

In 1999, Gary Carr introduced an OM that had Galilean optics and that was ergonomically configured for dentistry, with several advantages that allowed for easy use of the scope for nearly all endodontic and restorative procedures.



### Fig:32 Current OM allows the doctor and the assistant to ergonomically view the same field. This OM is fitted with a 3CCD (charge coupled device) video camera and an assistant scope.

This OM had a magnification changer that allowed for 5 discrete magnifications (magnification 3.5–30), had a stable mounting on either the wall or ceiling, had angled binoculars allowing for sit-down dentistry, and was configured with adapters for an assistant‟s scope and video or 35-mm cameras. It used a confocal illumination module so that the light path was in the same optical path as the visual path, and this arrangement gave far superior illumination than the angled light path of the earlier scope. This OM gained rapid acceptance within the endodontic community, and is now the instrument of choice not only for endodontics but for periodontics and restorative dentistry as well.

### Positioning The OM-

In chronologic order, the preparation of the OM involves the following maneuvers :

* 1. Operator positioning
  2. Rough positioning of the patient
  3. Positioning of the OM and focusing
  4. Adjustment of the interpupillary distance
  5. Fine positioning of the patient
  6. Parfocal adjustment
  7. Fine focus adjustment
  8. Assistant scope adjustment.

### The OM And Clinical Procedures-

* Removal of dentin that may obscure the location of these orifices is also enhanced with better visualization with the DOM.
* Obstructions such as separated instruments deep within canals can be addressed.
* Examining fracture, crown margins, cement layers, subgingival defects, and caries extension are all enhanced.
* Modern endodontic surgical procedures demand a microscopic approach.
* It also improves the identification of extra canals and has been shown to be superior to the use of the naked eye and magnifying loupes for this assessment.
* lateral root repairs, perforation repairs, external cervical invasive resorption repairs, and other resorptive repairs also benefit from a microscopic approach.24

### Rod–Lens Endoscope (Jedmed, St. Louis, MO).

The use of a rod–lens endoscope in endodontics was first reported in 1979. In 1996, the rod–lens endoscope was recommended as a magnification instrument for conventional and surgical endodontic procedures.



### Fig:33 A rod–lens endoscope (Jedmed, St. Louis, MO).

The rod–lens endoscope is made up of rods of glass working in junction with a camera, light source, and monitor. The option of a digital recorder (either streaming video or still capture) may be added to the system for documentation.



### Fig:33 a Endoscope visual system (EVS) (Jedmed, St. Louis, MO).

It allows clinicians‟ greater magnification than that achieved with loupes or a microscope, with optical resolution comparable with that of microscopes and/or loupes. A fixed field of vision is defined as „„viewing a treatment field from one single angle and distance.‟‟ The use of the endoscope is therefore recommended for visualization of surgical endodontic treatment.

### Recommendation-

The recommended rod–lens endoscope sizes, for endodontic surgical application, are a 2.7 mm lens diameter, 70 angulation, 3 cm length rod–lens, and a 4 mm lens diameter, 30 angulation, and 4 cm length rod–lens.24 A pair of 2 to 2.5 loupes should be used for visualization prior to the use of the endoscope

### Advantages-

The visualization advantage, in surgical endodontic treatment, the endoscope provides over the microscope, is the ability to view a surgical treatment field in a nonfixed field of vision. This is defined as the ability to view a treatment field at various angles and distances without losing depth of field and focus

### Disadvantages-

Although the endoscope can be used as a visualization instrument for conventional endodontic treatment, it can be bulky and difficult to maintain a fixed field of vision compared with a microscope

### Points to be kept in mind-

Hemostasis of the surgical field must be obtained before the endoscope is used because the scope cannot provide a discernible image when placed in blood. The warmth of the blood can also create lens condensation and a blurred image.

Prevention - Use of suction and irrigation, or an antifogging agent, will eliminate the fogging effect. 25

### Fully Motorized Microscope System

A motorized microscope equipped with a CCD camera serves as optical sensor for the acquisition of three-dimensional information in the micrometre range, and for the visual control of the assembly manipulations. In order to visually serve the micromanipulator in executing its task of handling and assembling microstructures under the microscope, an accurate, automated autofocus system is required.

When all components are fully motorized, calibration through the imaging software is seamless. The software will align the focus point or drift between objectives, allowing the image to stay in focus when changing magnification. Full motorization also results in an overall increase in throughput due to the automation of many imaging techniques and reduced operator skill requirements as the system can be set up through software, allowing for a simplified interface and use. This will also improve repeatability of images and measurements between operators at varying skill levels.

* Additional functions and benefits that come with a fully motorized system include enhanced microscope control and communication, including better control of microscope functions such as observation method, objective lens selection, lighting conditions, and aperture control. Made possible through software or hand switches, this enhanced control provides a number of benefits to the operator including:
* Guaranteed calibration as the software will have feedback to which objective lens is in place when the image is captured
* Simplified microscope configuration setup through observation method selection in software. This allows for all microscope functions to be automatically set for predefined observation conditions. Example: DF condition would set the DF mirror turret, turn the lamp intensity to max, open the aperture stop to max, change to the DF objective lens, and possibly even set a focus point.
* The ability to read and load microscope values from captured images within imaging software. This allows you to set up the system in the exact same configuration as when the image was taken.
* An increase in ergonomics as operators no longer have to reach up to the microscope to make changes to magnification or image methods
* An increase in sample cleanliness as users no longer need to reach above the sample to make changes to objective lenses or observation methods

### A fully motorized microscope configuration has:

* 1. Fully motorized microscope frame
  2. Motorized XY stage (i.e., Prior, LUDL, Marzhauser)
  3. Motorized Z (focus)
  4. Motorized add-on Focus drive (if not already included on microscope frame)
  5. Stage controller (either an external control box or internal PC card)
  6. Joystick for XY control and possibly Focus control
  7. Digital camera for automated image acquisition
  8. Control software

### Motorized XY stage provides the following user benefits:

Ability to perform MIA (Multiple Image Alignment). Allows for large out-of-field- of-view image capture through stitching.

Ability to set and save location points for return inspection.

Motorized control is very ergonomic as the user can move the joystick to any location, or control all stage movement and values through software. You no longer have to reach under or next to the stage to move the sample.

### A motorized Z (focus) delivers the following operational enhancements:

Ability to perform EFI (Extended Focal Imaging). This allows you to capture multiple Z focus images to generate an all-in-focus image. Ideal for samples with great depths or heights.

Improved ergonomics as the focus is now motorized, keeping you from having to reach for focus knobs. This is done either with software control or joystick.

### Added measurement and analytical tools with a fully motorized microscope system:

Large area stitching allows for measurement of features too large to see in a single field of view.

Extended focal imaging creating an all-in focus image allows for 3D imaging and Z height or depth measurements.

An automated geometric measurement at multiple point locations improves measurement speed and removes the human element from the measurement process, thus improving repeatability of measurements.

### Motorized Nosepieces

As part of a fully motorized microscope system, motorized nosepieces can provide increased inspection speed. The rotational speed of motorized nosepieces is faster and safer than manual nosepieces, decreasing time between inspections while maintaining cleanroom compatibility. In most cases, motorized nosepieces are controlled via software, a frame button, or an independent handset.

### Handset for Tactile Control

Within a motorized microscope environment, an ergonomically designed handset can allow pushbutton control of the motorized functions of the microscope such as the selection of the objective lens and observation technique. The operator can also use this handset to switch between varying autofocus controls, manually fine-focus, adjust the retardation position in DIC, control lamp intensity, and lower the stage for sample exchange.

### Active Laser Autofocus

A motorized microscope system may be equipped with an active laser autofocus unit designed to improve the accuracy and speed of inspections. A multi-spot sensor enables a substantial increase in stability by eliminating the effects of vertical topography on the sample, providing even faster and more predictable results.

### Automatic Aperture Control

Within a motorized microscope, a motorized aperture stop can be interlocked with the objective lens, automatically adjusting for the objective lens in use. Image quality for every magnification is thus optimized, making routine inspections more comfortable for the eyes and more efficient for the operator.

### Advanced Imaging Software Integration

In combination with motorized scanning stages, advanced imaging software can be integrated into a motorized microscope system to enable the operator to easily stitch various images beyond a single view, furthering image acquisition and analysis possibilities

### ZEISS OPMI PROergo-

It offers a variety of convenient, motorized functions that support effortless handling and mechanical stability. The virtually free-floating system allows smooth and precise in an appealing, sleek and compact design.



**Fig34 ZEISS OPMI PROergo**

* 1. Motorized Varioskop- At the push of a button focus on the treatment field within a working distance of 200 - 415 mm for a better and comprehensive overview – all without having to move the OPMI or change your position.
  2. Motorized zoom Continuous magnification- The brightness setting adjusts automatically as you increase or decrease magnification levels.
  3. Magnetic clutches The Free Float Magnetic System offers smooth movement and precise, stable positioning. The push of a button on the handgrip releases the magnetic brakes.
  4. Ergonomically designed handgrips with function keys Control the focus and zoom and set the other configurable function buttons to operate brightness and SpeedFokus to control video recording.
  5. Foldable Tube f170/f260- For an ergonomically correct posture, even with extremely angled positions.
  6. Stereoscopic image Large visual field with widefield eyepieces (12.5x or 10x). Special diopter settings also make them suitable for eyeglass wearers.
  7. Xenon illumination This provides homogenous, high-contrast illumination of the treatment field and offers a light temperature characteristic of natural daylight. Two xenon lamps are included in the quick-change module

### ZEISS EXTARO 300

The Fluorescence Mode in ZEISS EXTARO 300 helps us to preserve as much of the healthy tooth substance as possible.



### Fig 35 ZEISS EXTARO 300

It has 3 modes-

1. Fluorescence Mode
2. TrueLight Mode
3. NoGlare Mode
4. Fluorescence mode- It is the first device combining caries detection technology with optical magnification, the Fluorescence Mode supports detection of carious tooth substances during excavation of previously opened cavities. It also supports you in distinguishing natural hard tooth tissue from the most widely used dental composite resin.
5. TrueLight mode- Prevent premature composite curing while working in a natural light environment. Similar to the existing Orange Color Mode, the TrueLight Mode does not cause premature polymerization of widely-used, contemporary light curing composites under the microscope, giving you more time to finish complex modeling tasks.
6. NoGlare Mode- Analyze and restore teeth without distracting reflections.

### C. ZEISS OPMI pico-

It is a compact, high- performance, easy-to-use surgical microscope.



### Fig 36 Zeiss OPMI pico

**Lens**

The lens projects an image of the object. To focus the image the surgical microscope can be raised or lowered, so long as the lens has been set to the working distance of e.g. 250mm from the object. The fine focus is used to focus precisely at higher magnification.

### Magnification changer

The magnification factor can be altered in order to gain an overview at lower magnification and a view in more detail at greater magnification. This can be achieved by turning the magnification changer.

### Tiltable Tube

Depending on the application the surgical microscope is used in different positions. In order to provide you with a comfortable and ergonomic view into the surgical microscope the tube head can be tilted.

### The eyepieces

The eyepieces are the interface between the surgical microscope and the human eye. They magnify the image and can add diopter corrections.

### Light intensity

To control the light intensity, turn the knob. The higher the magnification, the more light you will need. Moving up the surgical microscope activates the standby mode.

### The orange filters

The orange filter prevents premature hardening of composite material. This can place in the beam path when working with composite material. A green filter increases the contrast between the blood-filled and bloodless tissue, thus making details more visible.

### MORA Interface

It is a device which consists of co-observation tube which increases the distance between the eye-piece and eyes of the operator which prevents the straining of neck muscles.

It allows the OPMI pico to be tilted to the left or right. The eyepieces retain their horizontal position, so that you have a straight, ergonomic seating position when looking into the surgical microscope. Your head and upper body remain upright and relaxed.

The MORA creates a “posture-friendly” microscope system. To obtain the maximum benefits from the MORA Interface, the operator must be seated in the 12 o‟clock position. A microscope with a MORA Interface and a beam splitter increases the horizontal distance between the eyepieces and the long axis of the body of the microscope. It provides a horizontal working distance that is compatible with the distance between the top of the head and the mouth of the patient.

It makes working with a microscope more intuitive, more productive, and more enjoyable.

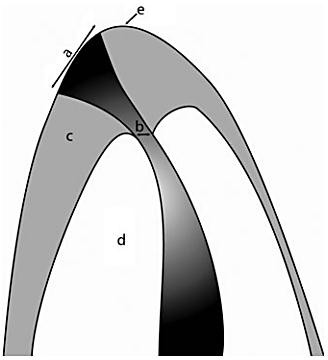
## WORKING-LENGTH DETERMINATION

Ideal pulp treatment is defined as the removal of infected pulp and cleaning, shaping, and disinfecting the root canal system. Subsequently, a three- dimensional filling can be provided. To achieve this goal, an essential stage is the assessment of the correct length of the root canals.

Working length is defined as the distance between the coronal/incisal reference point and the area that has been prepared and at which the filled canal should end.26

### Morphology of the root canal terminus

Kuttler (1955) concluded that a root canal had two main sections, a longer conical section in the coronal region consisting of dentine and a shorter funnel-shaped section consisting of cementum located in the apical portion. The shape of this apical portion is considered to be an inverted cone



### Fig:37 Idealized anatomy of apical portion of root (a) major apical foramen, (b) minor apical foramen (apical constriction) that may be coincident with the cemento-dentinal junction (CDJ), (c) cementum, (d) dentine and (e) root apex.

The most apical portion of the root canal system narrows from the opening of the major foramen, which is within cementum, to a constriction (minor foramen) before widening out in the main canal to produce an hour-glass shape.

The root canal terminus is considered by many to be the CDJ (Kuttler 1955, 1958, Ricucci 1998, Ponce & Fernandez 2003). Theoretically, the CDJ is the appropriate apical limit for root canal treatment as at this point the area of contact between the periradicular tissues and root canal filling material is likely to be minimal and the wound smallest (Palmer et al. 1971, Seltzer 1988, Katz et al. 1991, Ricucci & Langeland 1998). The term ‘theoretically’ is applied here because the CDJ is a histological site and it can only be detected in extracted teeth following sectioning; in the clinical situation it is impossible to identify its position. In addition, the CDJ is not a constant or consistent feature, for example, the extension of the cementum into the root canal can vary (Ponce & Fernandez 2003). Therefore, it is not an ideal landmark to use clinically as the end-point for root canal preparation and filling.27

In clinical practice, the minor apical foramen is a more consistent anatomical feature (Katz et al. 1991, Ponce & Fernandez 2003) that can be regarded as being the narrowest portion of the canal system and thus the preferred landmark for the apical end-point for root canal treatment. It is the border line between the dental pulp and periodontal area, which is approximately 0.5-1 mm from the anatomic apex.

Failure to determine the root canal length can result in both over- and underestimation of the root canal length. Overestimated working length can result in preparation beyond the apical isthmus, which can damage the peri- apical region. Underestimated working length and inadequate debridement can cause unsuccessful treatment and dissatisfaction of both the patient and dentist.28

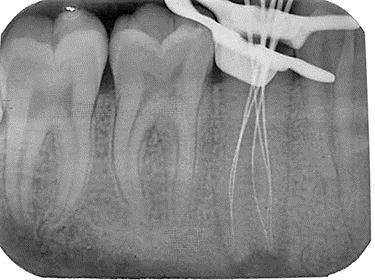
### Determining the root canal terminus

Several methods have been introduced as follows-

* Radiographs
* tactile sensation
* presence of moisture on paper points
* knowledge of root morphology has been used to determine the length of root canal systems

### Radiographic method

it is described by Ingle and is one of the most common and reliable methods used in determining the working length.



### Fig:38 Working length determination radiograph

**Limitations-**

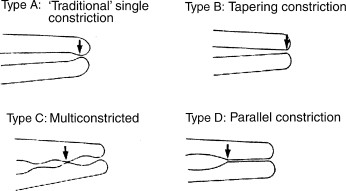
* 1. Accuracy is difficult to achieve in this technique because the apical constriction cannot be identified; and the variables in techniques, angulation and exposure distort this image and lead to error due to laterally situated foramina.
  2. Radiation hazard both to the patients and the dental personnel. The observer's bias in radiographic interpretation may lead to errors.
  3. Gives two-dimensional picture of a 3-dimensional object.
  4. It is well known that the major apical foramen is not always located at the radiographic apex of the root; rather, it often lies on the lingual/buccal or mesial/ distal aspect. If the major foramen deviates in the lingual/buccal plane, it is difficult to locate its position using radiographs alone, even with multiplane angles (Schaeffer et al. 2005).29

### Tactile Perception

Because of the simplicity of the technique, time-saving and its virtual effectiveness are factors that motivate a few clinicians in endodontic practice to still follow this technique.

### Limitations

This technique is in general inaccurate in root canals with immature apex, excessive curvature and if the canal is constricted throughout its length. And also the topography of the apical constriction can vary considerably from tooth to tooth.



### Fig:39 Varying topographies of the apical terminus (Dummer *et al*)

1. **Paper Point Technique**-

This has been well described by Rosenberg and is dependent on having achieved apical patency. This technique is based on the premise that the RCS of an uninfected tooth is dry while the external periodontium is wet, hydrated tissue. It has been suggested that the dry/wet interface should be the apical limit.

### Limitation

It cannot be used in cases where it is impossible to dry the canal (due to inflammatory exudate) or achieve apical patency.30



### Fig:40 Paper point placed in the canal

**D. Electronic Root Canal Working Length Determination**

It has become increasingly popular as it eliminates many of the problems associated with radiographic methods. The electronic apex locator (EAL) machine has attracted a great deal of attention because it operates on the basis of the electrical impedance rather than by a visual inspection. The EAL is one of the breakthroughs that brought electronic science into the traditionally empirical endodontic practice. EALs are particularly useful when the apical portion of the canal system is obscured by certain anatomic structures, such as impacted teeth, tori, the zygomatic arch, excessive bone density, overlapping roots, or shallow palatal vaults. Indeed, EALs currently are being used to determine the working length as an important adjunct to radiography. 30,31



### Fig:41 Root ZX Electronic Apex Locator

**Advantages-**

Its most important **advantage** over radiographic method is that it can measure the length of the root canal to the end of cemento-dentinal junction.

It is more accurate, easy and fast, with no requirements of X-ray exposures. 31

### History

* In 1918, Cluster32 first put forth the idea that the root canal length could be determined by using the electrical conductance.
* In 1942 when Suzuki reported a device that measured the electrical resistance between the periodontal ligament and the oral mucosa. He discovered that in dogs, the electrical resistance between the root canal instrument inserted into a root canal and an electrode applied to the oral mucous membrane registered a consistent value of approximately 6.5 KU.33
* In 1962, Sunada reported that a specific value of the resistance would determine the position of the root canal terminus. He determined that when the tip of an endodontic instrument had reached the periodontal membrane through the ‘apical foramen’, the electrical resistance between the instrument and the oral mucous membrane was approximately equal to 6.5 kµ. He also claimed that if the reamer perforated the canal wall or floor of the pulp chamber and reached the periodontal membrane, the electrical resistance between the mucous membrane and the perforated periodontal membrane was almost equal to the resistance shown at the apex

Additionally, he showed that if an endodontic instrument that is connected to an ohmmeter is introduced into the canal and advanced until the ohmmeter shows the value of 40 µA, the tip of the instrument has reached the periodontal ligament at the apical foramen. **The device by Sunada in his research became the basis for most EALs.**



### Fig:42 Simple d.c. ohmmeter for measuring the length of the root canal using direct electric current

Based on this fundamental principle, these resistance-based devices should be able to detect the periodontal tissue at the ‘apical foramen’. Clearly, they do not assess the position of the root apex and the name ‘electronic apex locator’ is not appropriate; ‘electronic apical foramen locator’ or ‘electronic root canal length measurement device’ (ERCLMD) as a generic name would be more appropriate.34

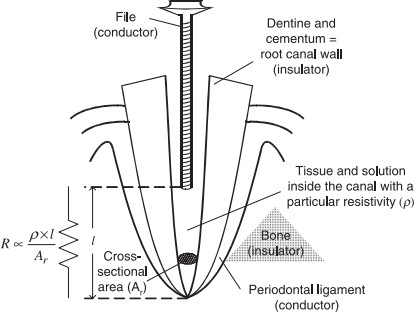
* In 1973, Inou , reported a modification that incorporated the use of an audiometric component that permitted the device to relate the canal depths to the operator via low-frequency audible sounds.
* By 1975, newer units such as the Neosono (Amadent, Cherry Hill, New Jersey) and many other resistance-type apex locators became available.
* In 1984, the difference method was introduced by Yamashita as a new principle of measurement. This method used two different frequencies for the first time with two matching resistances and impedances. The apical constriction was determined from the difference between the two.
* In 1991, Kobayashi and Suda improved this idea of relative impedance measurement and introduced the ‘ratio method’, creating an impedance quotient instead of a difference.34

### Operating principle of Electronic Apex Locator-35

Root canals are surrounded by dentine and cementum that are insulators to electric current. At the minor apical foramen, however, there is a small hole in which conductive materials within the canal are electrically connected to the periodontal ligament that is a conductor of electric current.

The resistive material of the canal (dentine, tissue, fluid) with a particular resistivity forms a resistor, the value of which depends on the length, cross- sectional area and the resistivity of the materials.

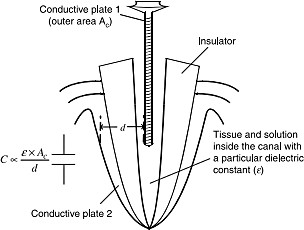
If an endodontic file penetrates inside the canal, and approaches the canal terminus, the resistance between the end of the instrument and the apical portion of the canal decreases, because the effective length of the resistive material inside the canal (*l* ) decreases.



### Fig:43 a The structure of the tooth during root canal treatment in terms of electrical conductivity, and the resistance of the model.

As well as resistive properties, the structure of the tooth has capacitive characteristics.

Assume the file, with a specific surface area, to be one side of a capacitor and the conductive material (e.g. periodontal ligament) outside the dentine being the other plate of that capacitor. Tissue and fluid inside the canal, in addition to the cementum and dentine of the canal wall, can be considered as separators of the two conductive plates and determine a dielectric constant (ε). This structure forms a capacitor, much more complex than symbolized in Figure.



### Fig:43 b The capacitance of the tooth during root canal treatment.

**This model represents a starting point upon which all EALs are based-**

An electrical circuit is formed that starts from the EAL, runs through a clip on an endodontic file, through the root canal, through the AC, out the PDL and finally through the mucosa and onto a clip on the patient’s lip. The circuit is complete when the current returns to the device. EALs extrapolate the position of the file in the canal by measuring the resistance, impedance, capacitance (or some variant or combination of these) in the electrical circuit formed.

### Classification of ERCLMD According to (Neekofar *et al*,2006)35

He reported that the devices did not assess the position of the root apex, that the name ‘electronic apex locator’ was not appropriate, and that ‘electronic root canal length measurement device’ (ERCLMD) as a generic name would be more appropriate.

1. Resistance-based ERCLMDs
2. Low frequency oscillation ERCLMDs
3. High frequency devices (capacitancebased devices) ERCLMDs
4. Capacitance and resistance ERCLMDs
5. Voltage gradient ERCLMDs (difference in impedance with three nodes)
6. Two frequencies, impedance difference ERCLMDs
7. Two frequencies, impedance ratio (Quotient) ERCLMDs
8. Multifrequency ERCLMDs

### Table 3. Categorization of electronic root canal length measurement devices

**According to Dental Clinics of North America, 2004 32-**

1. Traditional-type apex locators (resistance or impedance type)
2. Frequency-dependent apex locators
3. Apex locators with other functions

### Traditional-type apex locators (resistance or impedance type)

As the file approaches the periodontal ligament, the voltage change divided by the current (amperes) results in decreasing resistance, per Ohm’s law, until a value of 6.5 KW is reached. The accuracy of resistance-based apex locators can be high provided certain conditions are adhered to. Dry canals provided the most accurate readings.

The resistance-type EALs often yield inaccurate results when electrolytes, excessive moisture, vital pulp tissue, exudates, or excessive haemorrhage are present in the canal.

A new apex locator, the impedance type, was developed in the late 1980s to improve the resistance-type apex locators. The impedance-type EAL uses the electronic mechanism that the highest impedance is at the apical constrictor, which is the narrowest portion of the canal where the impedance changes drastically, when a canal is thought of as being a long hollow tube. The

Endocator (Hygienic Corporation, Akron, Ohio) was an example of an impedance-type apex locator.

Some examples- Sono-Explorer (Union Broach, New York, New York)

Neosono (Amadent, Cherry Hill, New Jersey) Endocator (Hygienic Corporation, Akron, Ohio)



### Fig:44 Endocator (Hygienic Corporation, Akron, Ohio)

1. **Frequency-Dependent Apex Locators**

The newest type of EAL was introduced in the early 1990s in an effort to obtain a more accurate canal length measurement in various canal circumstances. It uses more advanced technology and measures the impedance difference between the two frequencies or the ratio of two electrical impedances.

In 1990, Yamashita reported on a device that calculated the difference between two impedances from two different frequencies, which were generated with composite sine wave current sources, and was marketed as the Endex (Osada Electric Co., Tokyo, Japan). It works by comparing the difference in impedances using the relative value of two alternating currents at frequencies of 1 and 5 kHz. As the file moves toward the apex, the difference becomes greater and shows the greatest value at the apical constricture, allowing for a measurement of that location. 36



### Fig:45 Endex (Osada Electric Co., Tokyo, Japan)

**Advantages**

* Easy to operate
* Operates in fluid environment
* Operates with RC prep
* Low voltage electrical output

### Disadvantages

* Must calibrate each canal
* Sensitive to canal fluid level
* Needs fully charged battery

Some Examples- Apex Finder Model 7005 (Analytic Endodontics, Orange, California)

Root ZX (J. Morita Corp., Tustin, California)

Bingo 1020 (Forum Engineering Technologies, Rishon Lezion, Israel)

### Apex locators with other functions

EALs with additional functions were developed in the late 1990s. The Solfy ZX (J. Morita Corp.), which is a combination of an ultrasonic hand piece and a Root ZX, was designed to prevent over-instrumentation by stopping the ultrasonic vibration when the file reaches the required location.

Devices that combine an apex locator and an electrical pulp tester also have been marketed. One example is the Elements Diagnostic Unit (SybronEndo, Orange, California).32

### Technique for Calculating Working Length Using the Resistance Locators.37

1. Turn on the device and attach the lip clip near the arch being treated. Place a size 15 file into the reamer/file holder. Use a file with a plastic handle (metal-handled files need insulators) that is 25 mm long, unless the tooth is very short, so that you have enough metal protruding through the tooth to attach the file clip (for very long teeth, use a 31 mm file). Insert the tip of the file approximately 0.5 mm into the sulcus of the tooth to be treated, similar to the placing of a periodontal probe. Adjust the control knob until the reference needle is centered on the meter scale and produces audible beeps. Set the holder aside until needed to record the measurement.
2. Irrigate the canal and remove any pulp tissue, debris, foreign material, unwanted items, and so forth that are present with broaches and Hedstrom files.
3. Using the preoperative radiographs, estimate the working length and canal width. Using the instrument calculated as correct for width; set the stop at the estimated length. The canal should be slightly wet with irrigant (hydrogen peroxide or sterile water is better here than hypochlorite solutions, which are ionizing).
4. Insert the file slowly into the canal until the reference needle moves from the extreme left to the center of the scale and the alarm bleeps sound. This should happen near the site where you have placed the stop if your estimate has been accurate. Reset the stop at the reference point (later in this chapter), remove the file, and record the length.
5. Take a radiograph with the file in place at the length indicated by the locator and examine the resulting film. If the suggested length is considerably longer or shorter than your estimate, it is possible that the preoperative films were elongated or foreshortened, or that the apex

locator has been inaccurate. Using the film with the file in place, attempt to reconcile the differences and arrive at a logical working length.

### CLASSIFICATION ACCORDING TO THE GENERATION38-

1. **The First Generation (Resistance Type**):

These are also known as Resistance Based Apex Locator, measures opposition to the flow of direct current or resistance. These devices were found to be unreliable when compared with radiographs, with many of the readings being significantly longer or shorter than the accepted working length.



### Fig:46 Resistance based apex locator

1. **Root Canal Meter (Onuki medical Co. Japan)-**

It was developed in 1969. It used the resistance method and alternating current as a 150 Hz sine wave. Pain was often felt due to high currents in the original machine, so improvements were made and released as the Endodontic Meter and the Endodontic Meter S II (Onuki Medical Co.) which used a current of less than 5 lA.38

### Endodontic Meter S II (Onuki Medical Co., Tokyo, Japan)-

This device uses micropower operational amplifiers so that battery consumption is minimized. The device works for more than 1 year without a

replacement of the battery and is hardly affected by changes in room temperature. The measurement uses a current of less than 5 ~tA .31

### Dentometer (Dahin Electro medicine, Denmark) and the Endo Radar (Electronica Liarre, Italy) –

It was not as popular as it gave inaccurate readings in wet canals, obstructed canals, in carious/ defective restorations, in case of perforations and in patients with cardiac pacemakers. Also when the instruments came in contact with metallic restorations, false readings.39

### Advantages

* + Easy to operate
  + Uses K-type files
  + Digital readout
  + Detects perforations
  + Built in pulp tester
  + Requires a dry environment
  + There should be no caries or defective restorations

### Disadvantages-

* + Requires calibration
  + Requires a lip clip with good contact
  + Patient sensitivity
  + Perforations can give false readings
  + Contraindicated in patients with pacemakers

### The Second generation (Impedance Type)-

It was developed in the late 1980s to improve the resistance-type apex locators. The impedance-type EAL uses the electronic mechanism that the highest impedance is at the apical constricture, which is the narrowest portion of the canal where the impedance changes drastically, when a canal is thought of as being a long hollow tube.

### Principle

Tooth simply becomes a small diameter long hollow rube, with low resistance in the coronal portion, and a high resistance value in the apical region of transparent dentin. At the end of the tube, which corresponds to the end of the tooth, there is a sharp decrease in the induced resistance value. The end of the tube is then analogous to the apical foramen. By using an insulated probe with an exposed tip, the total surface area of the tip is infinitely small in comparison to the total probe area. This allows detection of small tube- induced impedance even in the presence of electroconductive solutions.40

Second generation apex locators were of the single frequency impedance type which used impedance measurements instead of resistance to measure location within the canal. Impedance is comprised of resistance and capacitance and has a sinusoidal amplitude trace. The property is utilized to measure distance in different canal conditions by using different frequencies.

### Sono-Explorer (Hayashi Dental Supply, Tokyo, Japan )-

The change in frequency method of measuring was developed by Inoue in 1971 which calibrated at the periodontal pocket of each tooth and measured by the feedback of the oscillator loop,40



### Fig:47 Sono-explorer

The beeping of the device indicated when the apex was reached, so some clinicians erroneously thought that it measured by using sound waves.

### Disadvantages

* more time consuming than radiograph and less accurate.41

A later model, the Sono-Explorer Mk III uses a meter to indicate distance to apex (Inoue & Skinner 1985)

### NeoSono D(Amadent Corp., Cherry Hill, N J)

The manufacturer of the Neosono-D electronic apex Iocator claims that it possesses more sophisticated circuitry than did the earlier electronic apex Iocators. This sophisticated circuitry supposedly helps to eliminate sources of error.42



### Fig:48 NeoSono D (Amadent Corp., Cherry Hill, N J)

The device cannot be expected to provide accurate readings in canals with undeveloped or "blunderbuss" apices.

### Endocater (Yamaura Seisokushu, Tokyo, Japan)

A high frequency (400 kHz) wave measuring device, the Endocater was introduced by Hasegawa *et al*. (1986). With an electrode connected to the dental chair and a sheath over the probe it was able to make measurements in canals even with conductive fluids present.



### Fig:49 Endocater (Yamaura Seisokushu, Tokyo, Japan)- Disadvantages-

The sheath caused problems because it would not enter narrow canals, could be rubbed off and was affected by autoclaving.43

This device used a large file coated with Teflon, which was difficult to use in narrow canals; in addition the Teflon peeled off in curved canals.

### Digipex I, II and III (Mada Equipment Co., Carlstadt, NJ, USA)-

It also combined a pulp vitality tester with apex locator. Czerw et al. in 1995 found the Digipex II to be as reliable as the Root ZX in an *in vitro* study.38



### Fig:50 Digipex II

1. **Exact-A-Pex (Ellmann International, Hewlett, NY, USA)-**

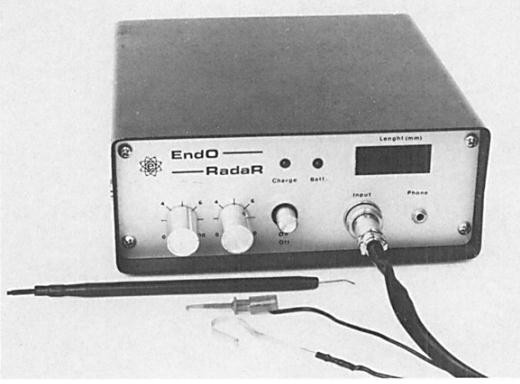
Uses an audio and a light emitting diode (LED) display. It was found that the Exact-A-Pex always duplicated the canal length as determined by visualizing

the tip of a file at the foramen of extracted teeth (Czerw *et al*. 1994). Hu¨lsmann & Pieper (1989) found the Exact-A-Pex measured consistently short in immature teeth requiring apexification, but was able to give correct results at the time of obturation, comparing results with radiograph.38

### Endo Radar (Elettronica Liarre, Imola, Italy)-

This is a battery powered electronic root canal measuring device which indicates the distance of the instrument tip from the anatomical foramen in tenths of a millimetre via a digital display. It also indicates the distance past the apex via a flashing readout when over-instrumentation occurs. A sound modulator can also be used.

In a study done by PV Abbott, 1987 it was found radiographic techniques to be quicker than using the Endo Radar.41



### Fig:51 Endo Radar

**Disadvantages-**

Electrolytic/ionic solutions such as sodium hypochlorite are contra-indicated as they interfere with signal transmission. The manufacturers recommended distilled water, hydrogen peroxide or local anaesthetic solution as irrigants.

According to the manufacturer, roots filled with 'insulating material' or 'excessive necrotic tissue' may give a higher reading while the instrument is passing through the full length of the material before giving a true reading.41

### Formatron IV (Parkell Dental, Farmingdale, NY, USA)

It is a small simple device with an LED display. It uses an AC current and measures impedance to measure the distance of the file tip to the apex. It has also had variable results in terms of accuracy. 38 Himel (1993) found it to be accurate to ±0.5 mm from the radiographic apex 65% of the time and within 1 mm 83% of the time. 44



### Fig:52 Formatron IV apex locator

**Advantages**

* + Operate in fluid environment
  + Analogue meter
  + No patient sensitivity
  + Operated with RC Prep
  + No lip clip
  + Detect bifurcated canals
  + Detect peroration

### Disadvantages-

* + Requires calibration
  + Requires coated probes
  + No digital readout
  + not work with sodium hypochlorite or other conductive irrigants.

Gyorfi *et al*. determined the working lengths of 10 canals using radiographs and then compared these findings with four different apex locators. The Root

ZX and the Foramatron (Parkell Co., Edgewood, NY) agreed with the radiographic analysis in all 10 canals. 43,44

### THE THIRD GENERATION (FREQUENCY DEPENDENT COMPARATIVE IMPEDANCE TYPE)-

Third generation apex locators are similar to the second generation except that they use multiple frequencies to determine the distance from the end of the canal. These units have more powerful microprocessors and are able to process the mathematical quotient and algorithm calculations required to give accurate readings.

### Apit/ Endex (Osada Electric Co., Tokyo, Japan)-

In Europe and Asia, this device is available as the Apit.38

In 1984 Yamaoka et al. reported the "relative values of frequency response method." They applied a 1 kHz rectilinear wave to the canal; they then picked up the 1 kHz basic wave and the 5 kHz modulated wave with two filters, rectified those two waves, and obtained the two direct potentials. They could detect the position of the apical constriction by calculating the difference between these two potentials in electroconductive conditions of the root canals. This method has been modified and commercialized as the Apit, which calculates the difference between two potentials of the root canal with composite sine wave current sources with two different frequencies. 31



### Fig:53 Apit (Osada Electric Co., Tokyo, Japan)

**Advantage-**

it is able to measure lengths with electrolytes in the canal

### Disadvantage-

it needs to be calibrated in each canal. Not accurate readings in dry root canal

It gives a combined accuracy of 81% to within ±0.5 mm of the apical foramen.45

In 1993, Frank and Torabinejad, using the Endex, took canal measurements of 99 teeth in vivo and were able to locate the file tip, in moist canals, to within

0.5 mm of the apical constriction in nearly 90% of the specimens.

Mayeda *et al.* studied the Endex to determine whether there were differences in accuracy in vital or necrotic cases in vivo, finding that there was no statistical difference based on pulpal status, and that generally file tips were found between +0.50 mm to 0.86 mm from the apical foramen.

### The Root ZX (J. Morita Co., Kyoto, Japan)-

The main shortcoming of early apex locators (erroneous readings with electrolytes) was overcome by Kobayashi et al. (1991) with the introduction of the **ratio method** and the subsequent development of the self-calibrating Root ZX.31



### Fig:54 Root ZX (J. Morita Co., Kyoto, Japan)

**Principle**

Ratio-method

This device measures the impedances of 0.4 kHz and 8 kHz at the same time, calculates the quotient of the impedances, and expresses this quotient in terms of the position of the file inside the canal. This quotient is barely affected by the electrical conditions inside the canal. The capacitance of a root canal increases significantly at the apical constriction, and the quotient of the impedances reduces rapidly as the apical constriction is reached.

Kobayashi & Suda (1994) showed that the ratio of different frequencies have definitive values, and that the ratio rate of change did not change with different electrolytes in the canal. The change in electrical capacitance at the apical constriction is the basis for the operation of the Root ZX and its reported accuracy. 32

### Accuracy

It has become the benchmark to which other apex locators are compared. It gives an accuracy of 90% to within 0.5 mm of the apical foramen or the CDJ, depending on the reference point used, with many studies reporting 100% accuracy if 1.0 mm is accepted.

The user manual of the Root ZX states that the machine detects the apical constriction. According to studies, Root ZX targets the narrowest part of the canal regardless of this being the apical constriction or being created by root canal preparation.38

### Precision of the Root ZX in relation to pre-operative pulp status-

The performance of Root ZX in vital and necrotic teeth has been compared and the findings indicated that the device was not affected by the pre- operative status of pulp.46

### Accuracy of the Root ZX in re-treatment cases

The residual root filling material occluding the dentinal tubules predisposes to a reduction in electrical conductivity and an increase in impedance, a factor potentially enhancing the electrical detection of the AF. WL determined by the

Root ZX before obturating the root canals and after removing the root fillings was not significantly different. The performance of the Root ZX was also not influenced by the type of the root filling material as the device performed similarly when the canals were previously filled with Resilon or gutta percha. Root ZX measurements were within ± 0.5 mm from the AF in 95% of the re-treated teeth and always within ± 1 mm from the AF.47

### Possible factors influencing the accuracy of Root ZX

Capacitance is affected by the electrical properties of the materials involved in the test system and by the system geometry itself. This implies that the accuracy of Root ZX might be affected by several factors that could be divided into tooth-related factors (pre-operative pulp status, tooth type, position of the AF, canal obliteration, and the size of apical diameter) and operative factors (coronal pre-flaring, presence or absence of irrigants, file size, file alloy, and mode of file operation, i.e. rotary or non-revolving).

The Root ZX needs no calibration. The microprocessor of the device corrects the calculated quotient so that the position of the file tip and the meter reading are directly related. This occurrence means that root canal enlargement can easily be performed while the length of the root canal is simultaneously monitored. 47

It still gives inconsistent readings in a wide-open apex canal, as do other conventional devices.

External root resorption altered the morphology of AF, and it was more frequently associated with the roots of necrotic teeth. The altered AF morphology could complicate WL determination. I*n vivo* studies reported that the Root ZX was capable of maintaining the files tips within the roots limits despite the presence of external root resorption. 48

### Effect of apical diameter on the Root ZX accuracy

The total area of the minor diameter affected the performance of Root ZX with the device being significantly more accurate in teeth with smaller minor diameter.

### Effect of canal obliteration on Root ZX function

The accuracy of Root ZX in canals with apical obliteration was compromised.

### Performance of the Root ZX in dry and irrigated canals

If the canal is too dry, the meter reading might not move until the file is in close proximity to the apex. Unstable Root ZX measurements have been linked to canal dryness.47,48

### Effect of file size on the performance of Root ZX

The use of a snugly fitted file is not necessary for optimum performance of the Root ZX. The Root ZX was used with a size 15 hand file to measure the length of canals with apical diameters ranging between 0.5-0.9 mm. About 90% of the measurements were 0-1 mm short of the actual length, while the rest of the recorded lengths were 1-2 mm short of it.

The accuracy of the Root ZX has been reported to range from 64% to 100%. If 1.0 mm difference is deemed acceptable, the accuracy is reported at 100%.

Welk *et al*. tested the accuracy of the five-frequency Endo Analyzer Model 8005 (Analytic, Sybron Dental, Orange, CA) against the Root ZX and found the latter able to locate the apical foramen ±0.5 mm over 90% of the time with a mean difference less the 0.2 mm, compared with the Endo Analyzer at over

1.0 mm. 49

### Root ZX-II (J. Morita Corp., Kyoto, Japan)-

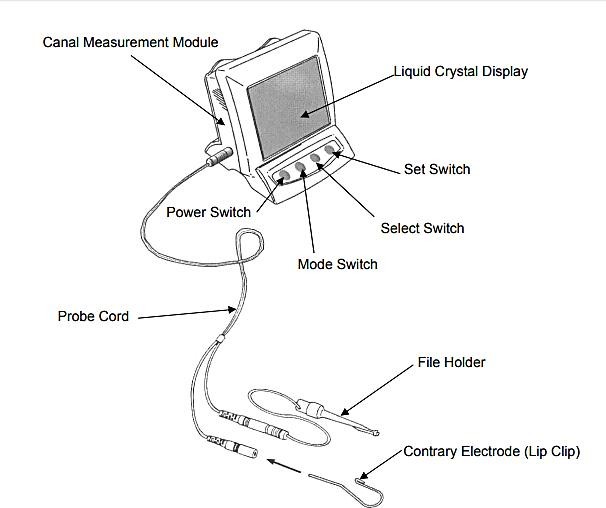
It is an EAL that the manufactures claim to be capable of measuring canal length without being affected by canal contents.

### Fig:55 Root ZX II

This device is composed of 2 modules:

* + 1. the canal measurement module
    2. the slow-speed hand piece module

The modules can be easily connected to the canal measurement module to perform root canal treatment while measuring the root canal. 50

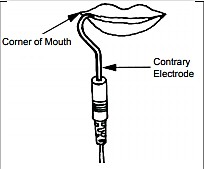


**Fig:55 a Parts of Root ZX Principle**- same principle of the original Root ZX.

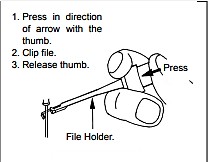
This high level of precision occurs because of the introduction of the ratio method. It uses multiple frequencies to determine the distance from the end of the canal. Besides that, the Root ZX-II still uses impedance measurements to measure location within the canal.

Finally, in the same manner as the original Root ZX, this equipment has more powerful microprocessors and is able to process the mathematical quotient and algorithm calculations required to give accurate readings.49,50

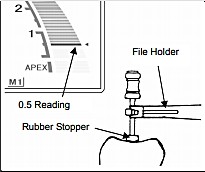
### Operating the unit- Fig- 55 b



1. Turn on the unit
2. Hook the contrary electrode at the patient’s mouth corner



3.Clip the file holder to the metal shift of the file



1. Insert the file until the meter reads 0.5. advance the file with slow clockwise turns until the word APEX begins to flash. When the apex is reached, turn the file with slow counter-clockwise turns until meter reads 0.5 again
2. Position the rubber-stopper on the tooth surface as a reference point to determine the working-length.

**Features-**

* It will measure in both wet and dry canal conditions with accuracy of 97.5%.
* The ratio technique used in the instrument provides a highly accurate detection of the file’s location. The accuracy of the measurement is not affected by the presence or absence of blood, other discharges, electrolytes, saline, tap water, or hydrogen peroxide.
* Automatic calibration ensures accuracy and eliminates the effect of changes in temperature, moisture, etc. inside the canal, even during treatment.
* The large color LCD screen is easy to read and provides a clear progressive display with high contrast. The action of the meter in the display corresponds exactly to the tactile sensation of using the file.

### Limitations-

**Accurate measurements cannot be obtained with the root canal conditions mentioned-**

1. Root canal with large apical foramen
2. Root canal with blood, saliva or a chemical solution overflowing from the opening.
3. Broken crown and a section of gingival tissue intrudes into the cavity
4. Fractured tooth
5. Re-treatment of a root filled with gutta-percha- GP should be removed completely to eliminate it’s insulating effect.
6. Blocked canals
7. extremely dry canal
8. Pulp tissue inside the canal

### Solfy ZX (J Morita Corp.)-

In 1994, Solfy ZX was developed as an ultrasonic root canal preparation system, which can measure the length of the canal through a handpiece and file. This model combined an ultrasonic handpiece and a Root ZX, which is designed to prevent over-instrumentation by stopping the ultrasonic vibration when the file reaches a preset location.51



### Fig:56 Solfy ZX d.TriAuto ZX (J Morita Corp.)-

In 1996, Tri auto ZX, is a cordless handpiece with an integrated apex locator and designed for rotary canal preparation with nickel-titanium instruments based upon ‘ratio-method’ This device does not require calibration because a microprocessor corrects the calculated quotient and the position of the file tip is showed on the panel.



### Fig:57 TriAuto ZX

The location of the file tip is indicated by LEDs on endo handpiece and by audible signal. The handpiece will automatically shut off after three minutes of non-use. This endo motor with apex locator by Morita, the ZX Mini make a great set of endo equipment for root canal treatment. *In vitro* studies ([Campbell *et al*. 1998](https://onlinelibrary.wiley.com/doi/full/10.1046/j.1365-2591.2002.00505.x?casa_token=SNyiv0cuZFcAAAAA%3AhZoBNBRuHloF2IX8fpjigjQMmEQvvdOBliFlqfMFSGk-3dV1zNGLVRH0tzSohAQfN9Q8qfECliMYxhY&b8), [Grimberg *et al*. 1998](https://onlinelibrary.wiley.com/doi/full/10.1046/j.1365-2591.2002.00505.x?casa_token=SNyiv0cuZFcAAAAA%3AhZoBNBRuHloF2IX8fpjigjQMmEQvvdOBliFlqfMFSGk-3dV1zNGLVRH0tzSohAQfN9Q8qfECliMYxhY&b9)) have demonstrated that the Tri Auto ZX can accurately measure the root canal length and trigger reversal of file rotation when the instrument reaches a predetermined level.38

### Advantages

* The accuracy of the measurement is not affected by the presence or absence of blood, other discharges, electrolytes, saline, tap water, or hydrogen peroxide.
* No Zero calibration. It insures accuracy and eliminates the effects of changes in temperature, moisture, etc. inside the canal even during measurement.

There is no difference between Dentaport ZX and Root ZX mechanism, except that the Dentaport ZX has an available port for attachment of endomotor.

### The Apex Finder AFA (all fluids allowed) ( Analytic Technologies, Redmond, WA)-

This machine claims to have five signal frequencies and to read four amplitude ratios. The unit is self-calibrating and can measure with electrolytes present in the canal. 38



### Fig:58 Apex Finder AFA

Pommer *et al*. (2002) found using radiographic methods in vivo that 86% of file tips were located 0.5 mm from a point 1 mm from the radiographic apex. It is able to detect the apical constriction in 76.6% of necrotic canals but was effective for 93.9% of vital canals. 52

McDonald *et al*. (1999) reported an accuracy of 95% in locating to within 0.5 mm of the CDJ in patients.

### The Neosono Ultima EZ-

It is known in the Southern Hemisphere as the DatApex (Dentsply Maillefer, Ballaigues, Switzerland). It is the successor to the Sono Explorer line of apex locators and uses 5 number of frequencies (0.5, 1, 2, 4, 8 kHz) to sample the canal using the best two for its reading. 32



### Fig:59 Neosono Ultima EZ

De Moor *et al*. (1999) found this unit to be 100% accurate in the ±0.5 mm range in an in vitro model with dry and wet canals with sodium hypochlorite.

It is least susceptible to operator influence compared with the Apit and Apex Finder AFA (De Moor *et al.* 1999).

It was 94% accurate with nickel-titanium files and 91% with stainless steel files. 49

### Apex Pointer (MicroMega, Besanc¸on, France)-

**Features:**

* Lightweight, compact and wireless.
* Electrodes autoclavable.
* APEX POINTER TM + works automatically without setting.
* Change sound frequencies to indicate progress to the apex between the apical constriction and the apex (foramen).



### Fig:60 Apex Pointer

**Benefits:**

* Easy to use.
* Requires no calibration and is ready for use immediately after the self test.
* Accurate, reliable and instant whatever the canal anatomy.
* Location apical accurate regardless of the channel content (dry, wet, blood, pus, pulp, etc ..)
* Differentiation of the instrument position (apical foramen and constrict).

In the presence of too much hypochlorite in the coronal part and in the channel, it will show an "overfilling" but will not give a false indication.

### h.Endo Analyzer Model 8005 (Analytic/Endo, Orange, CA, USA)-

Uses five different frequencies- 0.5kHz, 1kHz, 2kHz, 4kHz, 8kHz

* It is both a pulp tester and a root canal apex locator.39

### Fig:61 Endo Analyzer Model 8005

**Features:**

* + 2 self-calibrating apex location programs
  + Apex location feature can be set to read short of anatomical apex, if desired.
  + Large, easy-to-read display
  + Audible chime when foramen is reached

### Benefits:

* + Pain-free scanning function
  + Extremely easy to use
  + Convenient cleaning and disinfection.

### Endy (Loser, Leverkusen, Germany). –

Haffner et al. evaluated *in vivo* the accuracy of Endy to determine the working length. They reported that the limit ±0.5 mm from the AC was attained by the Endy in 67%of all measurements.

### Apex NRG blue (Medic NRG Ltd, Tel Aviv, Israel)-

It is a novel miniature apex locator which is a multi-frequency 3rd generation apex locator with a blue tooth attachment. The technology of this apex locator is based on digital processing (DSP) and uses square multi-frequency currents.



### Fig:62 Apex NRG blue

**Features-**

* + Display and storage of measurement data on computer is via Bluetooth Wireless Technology. Measurement data can be saved in the patient’s file. The results are seen on-line simultaneously on both the display on the apex locator and any screen connected to a computer.
  + This can be used both in dry and wet conditions.
  + NRG blue contains two colour LED light signals orange and blue. The acoustic signal (alarm) gives the indication of reaching the apex.

### Root ZX mini (J Morita Corp.)

It is built on the industry standard Root ZX technology. It works in both wet or dry canal conditions. Despite its compact size, the LCD display screen has maintained excellent readability with a clear, progressive display and high contrast.



### Root ZX Mini

It is the compact version of the Root ZX II, which is claimed to be the world's best-selling apex locator. It comes along with 3 programmable memory settings and other features such as shock resistance, automatic calibration, and power off function.

Features-

* + **Accurate Measurement**- It utilizes the ratio technique to provide a highly accurate indication of the location of the file inside the root canal. The accuracy of the measurement is not affected by the presence of blood, irrigant or other fluids such as electrolytes, saline, tap water or hydrogen peroxide. It has an evaluated accuracy of 97.5% according to studies.
  + **No Zero Adjustment** is necessary to accurately measure the length of the individual canals.
  + **Automatic Calibration** offered by this device ensures accuracy and eliminates the effect of changes inside the canal, such as in temperature, moisture, etc. even during endodontic treatment.

Ebrahim *et al*. (2007) stated that blood in canal adversely affects the readings of Root ZX mini and Apex ID. On the contrary, Herrera (2011) demonstrated that presence of blood does not influence the accuracy of apex locators when the foramen was sufficiently small.

According to G. Herverth (2015), Under the *ex vivo* conditions, Root ZX Mini and Raypex 6 were precise in locating the apical foramen in mesial canals of lower molar and buccal canals of upper molar teeth, with the same reliability as the digital radiographs of the extracted roots.

According to Aguiar *et al* (2017), concluded that the three models of the Root ZX EFL demonstrated similar and adequate precision when performing root canal length measurement at the apical foramen level.

### THE FOURTH GENERATION-

Uses two or more non-simultaneous continuous frequencies in order to measure the difference or ratio between two currents.

### Bingo 1020/Ray-Pex 4 (Forum Engineering Technologies, Rishon Lezion, Israel)



**Fig:63 Ray-Pex 4 (Forum Engineering Technologies, Rishon Lezion, Israel)**

It displays a 3D view of the root canal**. Mechanism**-

Similar to the third generation of EALs, the device uses two separate frequencies, 400 Hz and 8 KHz, produced by a variable frequency generator. Unlike the latter devices, it uses only one frequency at a time. The use of a single frequency signal eliminates the need for filters that separate the different frequencies of the complex signal. This prevents the noise inherent in such filters and increases measurement accuracy.

In addition, the calculations of the position of the file tip in Bingo 1020 are based on measurements of root mean square (RMS) values of the signals. RMS expresses the energy of the measured signal and is more immune to various noises or signal distortions than other parameters of the signal, such as amplitude or phase, that are used in other devices.

The manufacturers claim that the combination of these two techniques increases the measurement accuracy and the reliability of the device. However, these claims have not been substantiated.

An *in vitro* study of the Bingo 1020 found it to be as reliable as the Root ZX and also user friendly

Tinaz *et al*. (2002a) found the Bingo1020 to be as accurate as the Root ZX in an in vitro study and easier for a beginner to use in pre-flared canals. This unit has subsequently been marketed by Dentsply as the Ray-Pex 4. 53

The Bingo 1020 compared favourably with the Root ZX regardless of canal contents or irrigant. Both were deemed more reliable than the radiographic interpretation. An *in vitro* study also found the Bingo 1020 and the Root ZX performed equally well in the hands of clinicians with varying degrees of experience.

### Elements Diagnostic Unit and Apex Locator (SybronEndo, Anaheim, CA, USA)-

It was designed in 2003.

### Mechanism

The device does not process the impedance information as a mathematical algorithm, but instead takes the resistance and capacitance measurements separately and compares them with a database to determine the distance to the apex of the root canal. It uses a composite waveform of two signals, 0.5 and 4 kHz, compared with the Root ZX at 0.4 and 8 kHz. The signals go through a digital-to-analogue converter to be converted into an analogue signal, which then goes through amplification and then to the patient circuit model which is assumed to be a resistor and capacitor in parallel. The feedback signal wave-forms are then fed into a noise reduction circuit.38



### Fig:64 Elements Diagnostic Unit

The manufacturer claims that directly measuring resistance and capacitance eliminates the potential of error.

It uses multiple frequencies to eliminate the influence of the canal conditions, which is similar to the Root ZX (50), thus permitting less sampling error per measurement and more consistent readings. A recent investigation has demonstrated a great level of accuracy of this EAL in usage *in vivo*.

It gives a high accuracy of exact rate (i.e., 95% at 1 mm until the apical foramen).54, 55

### Features and Benefits54

* Autoclavable cords and connectors
* Probes are gold plated to resist micro-corrosion
* Automatic calibration for a more accurate diagnosis
* Vitality Scanner provides pain-free electric pulp testing and accurate analysis in the presence of EDTA, sodium hypochlorite, blood, saline, water and hydrogen peroxide

Tselnik *et al*. recently tested the Elements Diagnostic EAL (Sybron Endo, Sybron Dental, Orange, CA) against the Root ZX in vivo. Both devices were accurate to 75% of the time to ±0.5 mm from the minor diameter.

### ProPex (Dentsply Maillefer, Ballaigues, Switzerland)-

It is a multi-frequency-based apex locator which is based on the same principles of the other modern devices which use multiple frequencies to determine root canal length.



### Fig 65: ProPex

**Features-**

* + - calculation is based on the energy of the signal where the other apex locators usually use the amplitude of signal.
    - It displays the file progression in the root canal.
    - It works in dry and wet canals. It requires no calibration and no zero adjustment.
    - It is small, pocket sized device
    - The manufacturer does not specify any other technical characteristics and no studies are present in current literature on the ex vivo or in vivo accuracy of this EAL.
    - It was accurate in 100% of cases when determining the location of the apical constriction ±0.5 mm

Plotino *et al*. tested the Root ZX, the Elements Diagnostic Unit, and the ProPex unit and found their accuracy at 97.4, 94.3, and 100%, respectively, although the majority of the ProPex readings were beyond the apex.

### Novapex (Foroum Engineering Technologies Rishon Lezion, Israel) –

It utilizes voltage difference and operates on the principle that impedance measurement not only differs between two electrodes, depending on the frequencies used, but also differs greatly at an apical constriction region. There is lack of literature information about the accuracy of Novapex in determining the correct electronic working length.



### Fig:66 Novapex

In 2005, Goldberg *et al.* compared the Root ZX, the ProPex (Dentsply Maillefer), and the NovApex for accuracy in re-treatment cases. At 0.5 mm from the foramen, they reported an accuracy level of 95, 80, and 85%, respectively.56

### Apex DSP (Septodont, Saint-Maur des Fosse´s, Cedex, France)-

Utilizing sophisticated software, it immediately converts analog signals to digital format and transmits them via short cables. Other Apex Locators utilize

analog signals that are tranmitted over long cables, reducing the signal and increasing the exposure to distortion.



### Fig:67 Apex DSP

**Accuracy**

In comparison studies conducted at universities and research institutes around the world, Apex D. S.P was found to be more accurate than comparable instruments.

Apex D.S.P accurately locates the apex in all canal conditions including wet,dry and bleeding canals

### iPex (NSK Ltd, Tokyo, Japan)-

It was accurate in 90% of the samples at a position 0.5 mm short of the apical foramen.57

### iPex II (NSK Inc., Kanuma, Japan)

It is a multi-frequency EAL.

### Features-

* + Auto-detects the apex accurately in any conditions, dry or wet
  + compact body
  + when compared to other multi-frequency EALs, iPex II was found to be accurate in 50% of the specimens which is numerically inferior to other EALs 58



### Fig:68 iPex II

1. **The Fifth Generation Electronic Apex Locators-**

A significant disadvantage of the fourth-generation devices is that they need to perform in relatively dry or in partially dried canals. In some cases, this necessitates additional drying, and with heavy exudates or blood, the method becomes inapplicable. To cope with those problems, a measuring method has been developed based on comparisons of the data taken of the electrical characteristics of the canal and additional mathematical processing. Apex locators of this type, which are known as fifth generation devices.

Devices employing this method perform very well in the presence of blood and exudate. It measures the capacitance and resistance of the circuit separately. Devices employing this method experience considerable difficulties while operating in dry canals.39

### E-magic Finder-

5th generation apex locators were developed in 2003 as E-magic Finder series. It measures the capacitance and resistance of the circuit separately. It is supplied by diagnostic table that includes statistic of the file. They have best accuracy in any root canal condition (dry, wet, bleeding, saline, EDTA,

NaOCl) 38

### I-ROOT (E-Magic Finder) (S-Denti SEoul, South Korea)-

It measures the capacitance and resistance of the circuit separately. It is supplied by diagnostic table that includes the statistics of the values at different positions to diagnose the position of the file. Its unique patient

management software helps to measure the working length on the computer screen and printing it.

Works accurately in wet canals.

The Pulp-Chamber of the root canal should be visibly dry. The Root canal can be wet There Should be NO Metallic restoration in the tooth you are treating (Silver Filing, Crown, Bridge etc.) Always reach upto Anatomical Apex to achieve Apical Patency.

In i-Root it is displayed at 0.0 i-Root gives Accurate reading even at MINOR- APICAL DIAMETER. (58)



### Fig:69 I-Root Apex Locator

1. **Raypex 5 (VDW, Munich, Germany)-**

It is a frequency-based EFL, which measures the impedance at the frequencies of 0.4 kHz and 8 kHz, but uses only one frequency at each time interval and measurements are based on the mean square values of signals. The manufacturer claim that the combination of using only one frequency at a time and basing measurements on the root mean square values of the signals increases the measurement accuracy and the reliability of the device. The device uses the same 2 alternating current frequencies (400 to 8 khz) and determine the working length via impedance ratio.



### Fig:70 Raypex 5 apex locator

It shows a blinking red alarm when the file tip has just passed the apical foramen. The file tip is just withdrawn just to the point that the blinking apex indicator goes away indicating that the file is between major and minor foramen.59

It is able to locate the apical constriction predictably with (±0.5 mm) 80% accuracy. Stober *et al*., evaluated the clinical performance of Raypex 5 found that it is 75% accurate to ± 0.5 mm and 100% to ± 1mm.

### Propex II (Dentsply Maillerfer, Ballaiques, Switzerland)-

It uses multi frequency technology to locate the apical foramen with great precision under a wide range of canal conditions. Rather than using the amplitude of the signal as for all EALs, it measures the energy of the signal with multi signal frequencies.



### Fig:71 Propex II

It was 86.6% accurate considering 0.5 mm tolerance.

It was more accurate in detecting the apical foramen in bicuspids than in molars and anterior teeth.60

### The Sixth Generation Electronic Apex Locators-

The efficacy of 6th generation EALs in long term use yet to be established.

A major advantage of adaptive apex locator is eliminating necessity of drying and moistening of the canal. Adaptive apex locators continuously define humidity of the canal and immediately adapts to dry or wet canal. This way it is possible to be used in dry or wet canals, canals with blood or exudates. 39

### a.Raypex 6 (VDW, Munich, Germany)-

It is the last member of Raypex series. Manufacturer claims that it utilizes the latest multi-frequency apex locator technology and by this way displays precise results.

Folding so it can be protected whilst stored.

Root ZX and Raypex 6 are reliable in teeth with mature apices. At foramen diameters exceeding 0.57 mm, their accuracy is susceptible.



### Fig:72 RayPex6 Other uses of Electronic Apex Locators-

1. To detect root perforations to clinically acceptable limits
2. Determine the location of root and pulpal floor perforations
3. To detect horizontal fractures
4. To confirm suspected periodontal or pulpal perforations during pinhole preparation Recognize any connection between the root canal & periodontal membrane such as root-fracture, cracks & internal or external resorption.
5. Multiple-function apex locators are becoming more common and several have vitality testing functions.

Combination electronic apex locators and electric handpieces are also becoming common and are able to achieve excellent results with the same accuracy as the stand-alone units. 32,33

### Problems associated with the use of apex locators

1. The majority of present generation apex locators are not affected by irrigants within the root canal and the Root ZX has been found to be more accurate in the presence of sodium hypochlorite.
2. Intact vital tissue, inflammatory exudates and blood can conduct electric current and cause inaccurate readings so their presence should be minimized before accepting apex reading.
3. Canal shape, Lack of patency, the accumulation of dentine debris and calcifications can affect accurate working length determination with electronic apex locators. It has been suggested that prefacing of root canals as used in modern crown-down preparation techniques would increase the accuracy of reading.
4. Electronic apex locators have the potential to interfere with cardiac pacemakers. The manufacturer of electronic apex locators specifically warns against their use with patients with cardiac pacemaker. As there are many therapeutic uses and types of pacemakers some may not be influenced by apex locator use.32,38

### Clinical acceptance.

Use of the electronic apex locator to determine working length has still not gained widespread acceptance worldwide . This may in part be due to early devices which suffered from poor accuracy and did not function properly in the

presence of common irrigants. Cost of the instruments and exposure to the technology are also factors. The use of apex locators alone without a preoperative and postoperative radiograph is not a recommended practice due to the large variation in tooth morphology.32

### Disadvantages-

* Requires special device
* Accuracy is influenced by electrical condition of canal
* Difficult in teeth with wide-open apex Inconsistent results in cases of vital teeth (except newly developed devices.37

### CLEANING AND SHAPING IN ENDODONTICS

Cleaning and shaping represent an important step in the endodontic procedure.

Cleaning involves the removal of all organic substrates of the root canal system. These are the substances that can promote and support bacterial growth, such as pulpal remnants; body fluids, and food debris. Shaping means developing the canal into a continuously tapering cone.

Goals include debridement of the root canal by the removal of organic tissues and enlargement of the canal to create a suitable shape which facilitates debridement, irrigation, and canal obturation .

Although successful therapy depends on many factors, one of the most important steps in any root canal treatment is canal preparation.61

The main purpose of instrumentation is the mechanical debridement of the root canal system and the creation of a space for delivery of antimicrobial substances. Furthermore, a well-shaped root canal system facilitates the proper placement of a tight root canal filling to prevent re-colonization by oral microbiota. 62

In order to achieve these goals, various methods have been advocated to make the canal walls free of irregularities

Root canal preparation is performed with- reamers, files, burs, sonic instruments, mechanical apparatuses, and with nickel–titanium (Ni–Ti) rotary file systems.

Since most hand preparation techniques are time consuming and can lead to iatrogenic errors (i.e., ledging, zipping canal transportation, and apical blockage), much attention has been directed toward root canal preparation technique with Ni–Ti rotary instruments.63

Numerous studies have reported that they could efficiently create smooth, predetermined funnel-form shapes with minimal risk of ledging and transportation (Dantas, 1997, Esposito and Cunningham, 1995. The design

and high flexibility of Ni–Ti files allow instruments to closely follow the original root canal path, especially in curved canals.64

Nickel-titanium Instruments-

NiTi instruments are highly flexible and super elastic. Advantageously NiTi rotary shaping files have nearly eliminated the iatrogenic instrumentation complication that are often connected to endodontic steel instrument. NiTi instrument were introduced over two decade ago to improve the shaping and cleaning ability of root canals.Since their first appearance ,instrument design has changed considerably,progress has beenmade in manufacturing as well as alloy processing .Traditionally files has been produced according to empiric designs,and even today many instrument are still devised by individual clinicians rather than developed through an evidence-based approach.The development of a new files nowdays is a fast and market driven process

.Clinical procedure and ideal working parameters are still being refined as new instruments continue to be introduced to the market with a new versions rapidly becoming available ,the clinician may find it difficult to choose the file and technique most suitable for an individual case

NiTi instruments have undergone a revolution regarding different designs to produce an instrument that cuts effectively while exhibiting resistance to fracture even in the most challenging anatomical confines. One should always bear in mind that all files system have benefits and weaknesses. Each generation of instrument has something new to offer and been intended to improve upon previous generations. Ultimately clinical experience, handling properties, safety, and case outcome should decide the fate of a particular instrument design.

HISTORY

* 1963: W.F Buchler, developed Ni-Ti alloy while investigating non- magnetic, salt resisting, waterproof alloys for the space program.
* 1988: Walia et al reported the first potential use of NiTi in endodontics. No.15 files fabricated from Ni-Ti orthodontic alloy were shown to have 2-3 times the elastic flexibility in bending and torsion as well as

superior resistance to torsional fracture compared with No 15 stainless steel files manufactured by the same process.

* 1992: serene introduced Nickel-Titanium files to student sin the college of Dental medicine at the medical university of South Carolina.
* Light speed files were developed by Dr. Steve Senia and Dr. William Wildey in the early 1990s (1992)
* Profile system was introduced by Dr. Ben Johnson in 1994
* Greater taper (GT) files were introduced by Dr. Buchanan in 1998.
* Quantec 2000 files, followed by Quantec SC, the Quantec LX and the current K3 system were developed by Dr. McSpaddea
* Race was manufactured by FKG in 1999.
* ProTaper system was developed by Prof Pierre Machton, Dr. Clifford Ruddle and Prof John West in cooperation with Dentsply / maillefer (2001)
* M file – 2008.

PRINCIPLES OF NICKEL – TITANIUM ROTARY INSTRUMENTATION (34,35)

* Nickel-titanium instruments are not designed for negotiating small calcified or curved canals, or bypassing edges.
* Placing undue pressure on these extremely flexible instruments may lead to file breakage. This is attributable to the fact that Ni-Ti has less longitudinal strength and may deflect at a point where pressure is off the file.
* Stainless steel instruments should be used initially for pathfinding owing to their enhanced stiffness.
* Once the canal has been negotiated with at least a stainless steel No.15 K-type file or a ledge has been bypassed and removed, then rotary Ni-Ti instruments can be used.
* Stainless steel instruments are also more radiopaque than Ni-Ti and “show up” better in tooth length measurements.
* When using a gear reduction, slow-speed, Ni-Ti rotary handpiece, the clinician must always keep the handpiece head aligned with the long

axis of each canal as good straight-line access decreases excessive bending on the instrument.

* Ni-Ti rotary instruments must be used with light apical pressure and never be forced.
* Always be used in a lubricated canal system to reduce frictional resistance.
* Abrupt curvatures, S-Shaped canal systems, and canals that join must be avoided with any Ni-Ti rotary file their use in these cases may lead to breakage.
* As the Ni-Ti file experience any undue stress, including cyclic fatigued the metal undergoes a crystalline (microscopic) phase transformation and can become structurally weaker. In many cases, there is usually no visible or macroscopic indication that the metal has fatigued.
* A Ni-Ti file may disarticulate without any warning especially if not properly used.
* No one knows the maximum or ideal number of times the Ni Ti file can be used.

METALLURGY

The nickel titanium alloys used in root canal treatment contain approximately 56% nickel and 44% titanium. In some Ni-Ti alloys a small percentage (2%) of nickel can be substituted by cobalt. Recently, Boron was added to improve the surface hardness. The resultant combination is one to one atomic ratio of the major components and as with other metallic systems; the alloy can exist in various crystallographic forms. The generic term for these alloys is Nitinol; they have an inherent ability to alter their type of atomic bonding which causes unique and significant changes in their mechanical properties and crystallographic arrangement of the alloy. These changes occur as a function of temperature and stress.

The two significant features that are of relevance to clinical dentistry occur as a result of the austenite to martensite transition in the Ni-Ti alloys; these characteristics are termed shape memory and super elasticity.

* Super elasticity: It allows it to returns to its original shape upon unloading following substantial deformation. It exhibits 3 times the elastic flexibility in bending and torsion compared with stainless steel file
* Shape recovery: It demonstrates an ability to return to previously defined shape or size when subjected to an appropriate thermal procedure, approximately 125 degree centigrade.

Temperature induced phase transformation

The crystal structure of Ni Ti alloy at high temperature ranges (1000 c) is stable, body centered cubic lattice which is referred to as the austenite phase or parent phase. Nitinol has the particular characteristic that when it is cooled through a critical transformation temperature range (TTR), the alloy shows dramatic changes in its modulus of elasticity (stiffness), yield strength and elastic resistivity as a result of changes in electron bonding. By reducing the temperature through this range, there is a change in the crystal structure which is known as the martensitic transformation, the amount of transformation is a function of the start (Ms) and finish (Mf) temperature. This phenomenon causes a change in the physical properties of the alloy and gives rise to shape memory characteris. During this phase it forms the structure of a closely packed hexagonal lattice. Almost no macroscopic shape change is detectable on the transformation, unless there is application of an external force. The martensite shape, can be easily deformed to a single orientation by a process known as detwinning to detwinned martensite,when there is a „flipping over‟ of shear. The Ni Ti alloy is more ductile in the martensitic phase than the austenite phase The deformation can be reversed by heating the alloy above TTR (reverse transformation temperature range or RTTR) with the result that the properties of the Ni TI alloy revert back to their previous high temperature values. The alloy resumes the original parent structure and orientation as the B.C.C high temperature phase termed austenite with a stable energy condition. The total atomic movement between adjacent planes of atoms is less than a full interatomic distance when released on normal atomic lattice arrangements. This phenomenon is termed

as shape memory and allows the alloy to return to its previous shape, by forming strong, directional and energetic electron bonds to pull back displaced atoms to their previous positions; The effect of the transformation is instantaneous.

The transition temperature range for each nominal 55-nitinol alloy depends upon its composition, as this causes considerable variability in the number of electrons available for bonding to occur and is constant for a particular Ni Ti alloy composition. The TTR of a 1:1 ratio of nickel and titanium is in the range of -50 to +1000c.Reduction in the TTR can be achieved in several ways; In the manufacturing process both cold working and thermal treatment can significantly affect TTR.

Altering the nickel: titanium ratio in favour of excess nickel or by substituting cobalt for nickel atom also reduce the TTR. The TTR can be lowered by continued substitution of cobalt for nickel as cobalt possesses one less electron than nickel, thus lowering the total number of bonding electrons.However, formation of a detrimental second phase Ni Ti occurs if excess nickel is added in attempt to lower the TTR.

Stress induce martensitic transformation

The transition from the austenite to martensite phase can also occur as a result of application of stresses, such as occurs during root canal preparation. In most metals, when an external force exceeds a given amount, mechanical slip is induced within the lattice, causing permanent deformation. However with the Ni Ti alloys, a stress induced martensite transformation occurs rather than slip. This causes a volumetric change associated with transition from one phase to the other and an orientation relation is developed between the phases.

Spring back occurs when the stress decrease or stops without permanent deformation, and this spring back is defined as load per change in deflection, to the previous shape with a return to the austenite phase, provided the temperature is within a specific range.

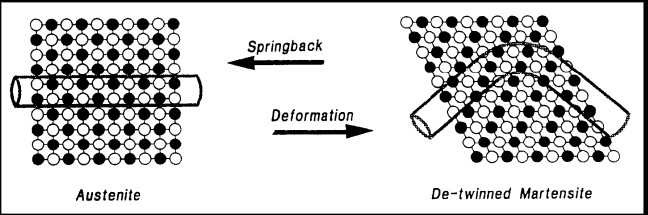


Fig 73 Stress induced martensitic transformation

The plastic deformation that occurs in Ni Ti alloys within or below the TTR is recoverable, within certain limits, on reverse transformation. It is this phenomenon of crystalline change which gives rise to the shape memory effect of the material and the superelastic behaviour.The part of the RTTR, in which shape recovery occurs, is termed the shape recovery temperature range (SRTR).This has also been termed “mechanical memory”. This is unlike conventional metallic stress strain behaviour, where elastic response in conventional alloys is recoverable, but is small in size, and where larger strains are associated with plastic deformation, that is not recoverable.

The super elasticity of Nickel Titanium allows deformation of, as much as 8- 10% strain to be fully recoverable, in comparison with a maximum of less than 1% with other alloys, such as stainless steel. Although other alloys such as copper-zinc, copper-aluminium, and gold-cadmium have been found to have super elastic properties, nickel titanium is the most biocompatible material and has excellent resistance to corrosion.

An alloy system is an aggregate of two or more metals which can occur in all possible combinations. As such, second groups of Nitinol alloys can be formed of the Ni Ti alloy contain more nickel and as these approaches 60% wt nickel an alloy known as “60-Nitinol forms”. The shape memory of this alloy is lower, although its ability to be heat treated increases. Both 55 and 60 nitinols are more resistant, tougher and have lower modulus of elasticity than other alloys such as stainless steel, Ni-Cr or Co-Cr.

The super elastic behavior of Ni Ti occurs over a limited temperature window. This temperature window, in which super elastic behavior is observed, is dependent on the precise chemical composition of the alloy. Addition of iron to Ni Ti lowers the temperature window. In endodontic application, where it is desirable to have the greatest superelastic behavior in a temperature range of 230c to 360c, a composition consistency of 50 atomic percent Ni and 50 atomic percent Ti is ideal.

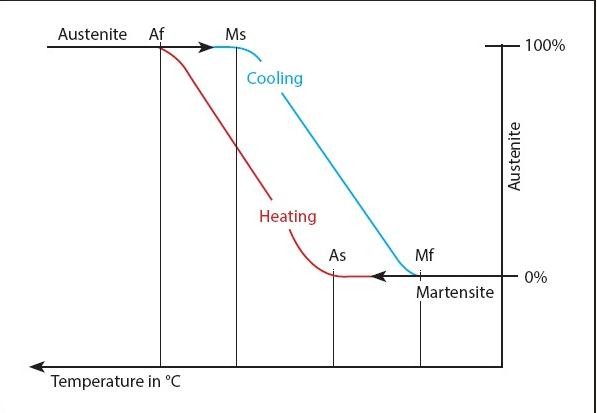


Fig 74 Temperature hysteresis in NiTi alloys. (As) austenite start temperature; (Af) austenite finish temperature; (Ms) martensite start temperature; (Mf) martensite finish temperature

The phase composition and consequently the mechanical properties of NiTi alloy are dependent on the ambient temperature and whether the alloy is cooled or heated to this temperature . If the temperature is above austenite ﬁnish temperature (Af), the alloy is in austenitic state, that is, it is stiff, hard and possesses superior superelastic properties. If the temperature is below martensite ﬁnish temperature (Mf), the NiTi alloy is in martensitic state, that is, it is soft, ductile, can easily be deformed and possesses the shape memory effect (12). Because of the reorientation capacity of the twinned phase structure, martensite has a superior cyclic fatigue resistance compared with austenite.3

Hence, a change in the transformation temperatures of the utilized NiTi alloy, which can be achieved by thermal and mechanical treatment or variation in the chemical composition (15,16,17), is the most important tool for manufacturers to alter the phase composition and consequently the mechanical properties of the NiTi alloy. The transformation temperatures are

usually examined by DSC (differential scanning calorimetry) analysis. Concerning the phase constitution, other techniques such as XRD (X-ray diffraction), metallographic examination and SEM (scanning electron microscopy) are needed to conﬁrm the ﬁndings of the DSC analysis.

NiTi raw wires are provided by manufacturers in a cold-worked state. Cold working signiﬁcantly increases the incidence of crystal lattice defects in NiTi alloy and results in a microstructure that contains residual martensite in an austenitic matrix with an impeded mobility of the martensite twin boundaries. Heat treatment of the cold-worked NiTi alloy in a temperature range around 450–550 °C is able to release the internal stresses and reduces the defects of the crystal lattice by giving the atoms enough thermal energy to rearrange themselves (18). Consequently, heat-treated NiTi alloy has signiﬁcantly increased cyclic fatigue resistance and higher transformation temperatures than not heat-treated NiTi alloy (18,19). Additionally to the heat treatment procedure, the superelastic properties of NiTi alloy can be trained by thermal cycling under mechanical stress (usually in a cold bath at about 0–10 °C and a hot bath at about 100–180 °C under constraint elongation at 1–4%) (20), resulting in an easier formation of the „trained‟ martensite upon loading (21). The mechanical properties, transformation temperatures and phase compositions of NiTi endodontic alloy are mainly inﬂuenced by the unknown, proprietary thermomechanical treatment rather than the elemental composition. A modiﬁed phase composition due to changed transformation temperatures is the main difference between thermomechanically treated and conventional NiTi alloy. Whilst conventional NiTi alloy contains austenite (10), thermomechanically treated NiTi alloy additionally contains varying amounts of R-phase and martensite under clinical conditions. These modiﬁcations are supposed to lead to more ﬂexible endodontic instruments with an advanced resistance to fracture

Austenitic NiTi alloy

To utilize the superelasticity of NiTi alloy, NiTi endodontic instruments should mainly consist of austenite phase (12). Austenite can betransformed to martensite by stress (e.g. insertion of the instrument into a curved root canal).

This effect is called stress-induced martensite (SIM) transformation . The transformation of the austenitic cubic crystal lattice to the martensitic monoclinic crystal lattice allows a complete recovery of the deformation up to 8% strain (10). Because the stress-induced martensitic state is not stable at the present temperature, unloading of the endodontic instrument (e.g. withdrawal of an instrument out of a curved root canal) leads to retransformation to the austenite phase and therefore to a spring-back of the endodontic instrument to its original shape . In addition to superelasticity, NiTi alloy possesses a lower elastic modulus compared with stainless steel resulting in an advanced ﬂexibility of NiTi endodontic instruments (Viana et al. 2010).

Conventional NiTi alloy

Conventional NiTi endodontic instruments approximately contain 56 wt% nickel and 44 wt% titanium (10). Hence, conventional NiTi endodontic instruments mainly consist of the austenite phase and possess superelastic properties. 62,63 These instruments have to be grinded rather than twisted . The grinding process may lead to defects on the surface of the NiTi instruments, which are supposed to have negative effects concerning fracture resistance, cutting efﬁciency and resistance to corrosion.

Electropolishing

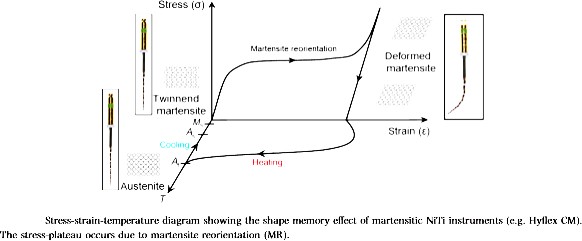
Electropolishing (EP) is an established ﬁnal surface ﬁnishing process for metal workpieces that allows for a controlled electrochemical removal of surface material leading to a smoother surface with increased gloss. During manufacturing of NiTi endodontic instruments, EP is used to remove surface irregularities, cracks and residual stress that are caused by the previous grinding process. This is supposed to improve fracture resistance, cutting efﬁciency and resistance to corrosion. Most studies indicated an advanced resistance to cyclic fatigue of electropolished versus non electropolished instruments. In accordance with these ﬁndings, SEM analysis of fractured surfaces revealed that the cracks of nonpolished instruments run along the machining grooves, whilst electropolished instruments exhibited a ﬁne irregular zigzag crack pattern.

M-Wire

With the aim to produce a more ﬂexible NiTi alloy with enhanced cyclic fatigue resistance, Sportswire LLC (Langley, OK, USA) developed a proprietary thermomechanical manufacturing procedure in 2007. The newly developed NiTi alloy was named M-Wire. The starting material for the heat treatment of M-Wire is a Nitinol composition consisting of 55.8 1.5 wt% nickel (Ni), 44.2

* 1. wt% titanium (Ti) and trace elements less than 1 wt% . The austenite ﬁnish temperature of M-Wire was found to be around 43–50 °C and consequently well above Af of conventional NiTi and body temperature, indicating that M-Wire is not completely composed of austenite under clinical conditions. According to this, various metallurgical laboratory techniques revealed that M-Wire contains austenite phase with small amounts of martensite and R-phase at body temperature . Hence, M-Wire maintains a superelastic state . M-Wire exhibits greater ﬂexibility than conventionally processed NiTi wire . It is known that the elastic moduli of martensite and R- phase are lower than that of austenite. Thus, improved ﬂexibility of M-Wire could be attributed to the presence of these two phases. Additionally, Pereira et al. (2012, 2013) found that the stress-strain curve of M-Wire exhibits a distinctive yielding phenomenon indicating that a stress-induced R-phase formation occurs prior to SIM transformation. As a result, M-Wire possesses a lower initial elastic modulus compared with conventional NiTi which can be seen by an initial lower inclination of the loading curve (Pereira et al. 2012, 2013). Furthermore, the stress-strain diagram shows that less stress is required to induce martensite transformation in M-Wire than in conventional NiTi.

Whilst maintaining comparable torsional properties (, M-Wire was found to be signiﬁcantly more resistant to cyclic fatigue compared with conventional NiTi alloy (37,38). The improved fatigue resistance could be explained by an enhanced resistance to fatigue-crack initiation because of the better reorientation capability of the martensitic variants.



R-phase

In 2008, shortly after the introduction of M-Wire, SybronEndo (Orange, CA, USA) developed another manufacturing process to create a new rotary NiTi system named twisted ﬁle (TF). The manufacturing procedure of TF includes three new methods: R-phase heat treatment, twisting of the metal wire and a special surface conditioning (39). The twisting process is conducted by transforming a raw NiTi wire in austenitic state through a proprietary thermal process into R-phase. R-phase possesses a lower shear modulus, and its transformation strain is less than one-tenth of that of the martensite transformation . Consequently, less stress is required to cause a plastic deformation in R-phase allowing the twisting process (Hou et al. 2011). After twisting, TF is converted back to austenite by additional thermal procedures to maintain its new shape (Hou et al. 2011). Meanwhile, two more NiTi systems with proprietary R-phase technology were introduced (K3XF, TF Adaptive; SybronEndo). In contrast to TF and TF Adaptive (TFA), the K3XF instruments are manufactured by traditional grinding process with a post-machining R- phase heat treatment. The twisted TFA instruments are used in a new adaptive motion technology allowing for either a rotary or reciprocating movement of the ﬁle depending on the intracanal torsional forces.

DSC analysis revealed that the austenite ﬁnish temperature of R-phase instruments is around 18–25 °C indicating that these instruments mainly contain superelastic austenite in the oral environment (Hou et al. 2011). In several studies, R-phase instruments revealed superior resistance to cyclic

fatigue and superior ﬂexibility compared with conventional NiTi without heat treatment . The load-deﬂection curve of TF instruments displays a narrower stress hysteresis including a lower plateau on loading than conventional NiTi, implying that less stress is required to induce SIM formation whilst more austenite can be transformed to martensite (Liaw et al. 2007). As a result of the enhanced ﬂexibility, the use of R-phase instruments allows a more centred canal preparation with less transportation than conventi0onal NiTi rotary systems. R-phase instruments reveal similar cyclic fatigue resistance in comparison with those made of M-Wire . Concerning torsional fracture, the R- phase instruments have a greater angle of deﬂection at failure but a decreased maximum torque compared with M-Wire and conventional NiTi instruments.

Martensitic NiTi alloy

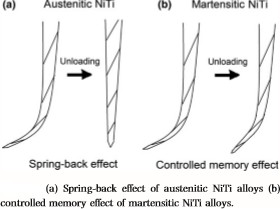
Martensite NiTi alloy is softer and more ductile than austenite. Additionally, it can easily be deformed and exhibits the shape memory effect when heated. The fatigue-crack growth resistance of the martensite phase was found to be superior to that of the stable austenite Shen et al. (2013a) considered that a hybrid (austenite-to- martensite) phase composition with a certain proportion of martensite is more likely to have favourable fatigue resistance. To produce endodontic instruments mainly containing the martensite phase, the transformation temperatures of the NiTi alloy have to be raised (e.g. by thermomechanical treatment). At a temperature above, the austenite ﬁnish temperature NiTi endodontic instruments consist of austenite. Upon cooling, a successive austenite-to-martensite transformation occurs beneath the martensite start temperature. The stress occurring during this cubic (B2) to monoclinic (B190) lattice transformation is released by twinning of the developed martensite (twinned martensite) without macroscopic form changes of the endodontic instrument. Twinned martensite can be plastically deformed under stress, leading to detwinning of the lattice structure (deformed martensite). This transformation from twinned to deformed martensite is called martensite reorientation (MR). Similar to SIM, the MR enables deformation up to 8% strain without signiﬁcant increase of stress (Kaack 2002). By heating the deformed instrument beyond the austenite ﬁnish temperature (e.g.

autoclaving), it will regain its original shape by returning to the primary austenitic state . Thus, martensitic instruments are pseudoplastic and exhibit the shape memory effect upon heating.

CM Wire

Controlled memory (CM) Wire which was introduced in 2010 is the ﬁrst thermomechanically treated NiTi endodontic alloy that does not possess superelastic properties at neither room nor body temperature (Zhou et al. 2012). Because of a modiﬁed phase composition, CM Wire instruments can be deformed because of reorientation of the martensite variants (47). Thus, in contrast to austenitic NiTi ﬁles, CM Wire instruments do not tend to fully straighten during the preparation of curved root canals. According to the manufacturer, this controlled memory effect is supposed to reduce the incidence of preparation errors. However,areduced root canal transportation for Hyﬂex CM compared with superelastic NiTi instruments (conventional NiTi, R-phase, M-Wire) was not conﬁrmed in several studies. Only compared to Revo-S (Micro-Mega, Besanc on, France), ProTaper Next (Dentsply Sirona Endodontics, Ballaigues, Switzerland) and Reciproc (VDW, Munich, Germany) Hyﬂex CM have signiﬁcantly less root canal straightening .DSC analysis revealed that the austenite ﬁnish temperature of CM Wire instruments is above intracanal temperature (around 47–55 °C) . Iacono et al. (2017) found that unused Hyﬂex CM instruments exhibit Af temperatures around 32–37 °C, whilst the Af temperature for used Hyﬂex CM instruments is about 54–61 °C. However, XRD analysis of Hyﬂex CM and Typhoon CM (Clinician‟s Choice Dental Products, New Milford, CT, USA) revealed that both new and used CM Wire instruments are a mixture of austenite and martensite structure with small amounts of the R-phase at room temperature . CM Wire instruments have greater ﬂexibility than M-Wire and conventional NiTi instruments . The improved ﬂexibility is mainly be attributed to the fact that the critical stress to induce martensite reorientation (twinned to deformed martensite) in martensitic instruments is much lower than the critical stress to induce SIM transformation (austenite to deformed martensite) in austenitic instruments. Despite increased ﬂexibility, which is considered to affect cutting efﬁciency negatively, Hyﬂex CM instruments have an enhanced cutting

efﬁciency in lateral action compared to electropolished and conventional NiTi instruments. CM Wire instruments have a signiﬁcantly enhanced cyclic fatigue resistance compared with M-Wire and conventional NiTi instruments which might be attributed to their martensitic state. CM Wire instruments exhibited a greater angle of deﬂection at failure than M-Wire and conventional NiTi, but the maximum torque was nearly equal



Gold and Blue heat-treated instruments

In 2011, Dentsply Tulsa Dental (Tulsa, OK, USA) introduced ProFile Vortex Blue, which was the ﬁrst endodontic instrument possessing a distinctive blue colour. There are now two Gold and two Blue heat treated NiTi systems available. Two of them are used in a rotary (ProFile Vortex Blue; ProTaper Gold, Dentsply Sirona Endodontics), and two of them are used in a reciprocating motion (Reciproc Blue, VDW; WaveOne Gold, Dentsply Sirona Endodontics). These instruments also exhibit a controlled memory effect and can be deformed . The main difference between CM Wire and the Gold, respectively, Blue heat-treated instruments is that these ﬁles are ground before they go through a proprietary post machining heat treatment . For Vortex Blue instruments, it is known that a visible titanium oxide layer is responsible for the distinctive blue colour that remains on the surface as a

result of the post-machining heat treatment (55). The austenite ﬁnish temperature for Vortex Blue was found to be around body temperature (38.5

°C), whilst the martensite start temperature is approximately 31 °C (Shen et al. 2015). Blue heattreated instruments exhibited less Vickers surface hardness than M-Wire instrument. Considering the controlled memory behaviour of the Blue heat-treated ﬁle, it can be assumed that despite lower transformation temperatures these instruments contain a greater amount of stable martensite than M-Wire, leading to a softer and more ductile NiTi alloy. At the moment, there are no studies available examining the phase composition by XRD, metallographic examination or SEM to conﬁrm this assumption. For Gold heat-treated instruments, a surface layer may also be responsible for the distinctive colour. DSC analysis of ProTaper Gold revealed approximately 50 °C for austenite ﬁnish temperature indicating that these instruments also mainly contain martensite or Rphase under clinical conditions. All Gold and Blue heat-treated ﬁles demonstrated enhanced ﬂexibility and fatigue resistance compared with conventional NiTi and M-Wire instruments, which might be attributed to their martensitic state. Only Hyﬂex EDM ﬁles have a signiﬁcantly increased cyclic fatigue resistance compared with ProTaper Gold, WaveOne Gold and ReciprocBlue . All four Gold and Blue heat-treated NiTi systems create well-centred preparation even in severely curved root canals. Kaval et al. (2016) reported that ProTaper Gold had a signiﬁcantly higher maximum torque than Hyﬂex EDM and ProTaper Universal (Dentsply Sirona Endodontics), whilst Hyﬂex EDM had an increased distortion angle. ProTaper Gold was found to be more effective in lateral cutting action than ProTaper Universal (58). This could be explained by the relatively harder surface layer of the Gold and Blue heat-treated instruments that might compensate the decreased microhardness.

MaxWire

Recently, FKG Dentaire introduced another proprietary thermomechanically treated NiTi alloy named MaxWire (Martensite-Austenite-electropolish-ﬁleX), which is the ﬁrst endodontic NiTi alloy that combines both shape memory effect and superelasticity in clinical application. At the moment, there are two instruments available that are made of MaxWire; the XP-endo Shaper and

XP-endo Finisher (both FKG Dentaire). Whilst these instruments are relatively straight in their Mphase (martensitic state) at room temperature, they change to a curved shape when exposed to intracanal temperature due to a phase transformation to A-phase (austenitic state) Thus, these instruments exhibit a shape memory effect when inserted into the root canal (M-phase to A-phase) and possess superelasticity during preparation. The curved shape is claimed to enable a preparation of complex root canalmorphologies with the potential to adapt to canal irregularities. The XP-endo Shaper revealed signiﬁcantly increased cyclic fatigue resistance compared with Hyﬂex CM, Vortex Blue and iRaCe (FKG Dentaire) (Elnaghy & Elsaka 2017b, Silva et al. 2018), but had less torsional resistance compared with Vortex (Dentsply Tulsa) and FlexMaster (VDW) (63,64). It is important to mention that the special low taper design (0.01) of the XPendo Shaper instrument profoundly affects its cyclic and torsional resistance. It is well known that a smaller diameter increases the cyclic fatigue and reduces the torsional resistance of NiTi rotary instruments . Because of the comparison of instruments with very different diameters, these studies might be of low evidence when comparing the mechanical properties of MaxWire to other NiTi alloy. At the moment, there are no studies available examining the transformation temperatures, phase composition and ﬂexibility of MaxWire instruments

### ADVANTAGES AND DISADVANTAGES OF NICKEL TITANIUM OVER STAINLESS STEEL

Advantages

* Nitinol files have 2-3 times more elastic flexibility than stainless steel
* Superior resistance to fracture in clockwise and counterclockwise tension owing to the ductility
* Ni Ti files can retain the shape of the curved canals and do not straighten like the stainless steel instrument.
* Ni Ti undergoes large amount of elastic deformation when compared to stainless steel
* Ni Ti files are biocompatible as indicated by trace element studies and have excellent anticorrosive properties
* Post treatment pain is greatly reduced by Ni Ti due to less incidence of ledges and perforation during their use.
* During autoclaving or dry heating Ni Ti instruments for sterilization, rotation to breakage studies indicate a transformation of residual martensite to austenite to restore the hardness of the instrument.

Disadvantages

* Cutting efficiency of nitinol is only 60% than that of a matching stainless file
* It does not give any indications before fracture
* Expensive when compared to stainless steel files
* It cannot adapt to sudden variations in speed resulting in fracture of the instrument.

FAILURE AND LIFE TIME OF NI TI INSTRUMENTS

* Ni Ti is unique in that it transforms from one phase to another (Austenite to martensite) and then returns to its original phase. When this stress induced phase transformation takes place, however, the external shape cannot be detected visually. It is there fore important that this file be carefully monitored for failure and fatigue.SCM has been used to study the initiation of fatigue failures in the laboratory.
* One hypothesis regarding the fracture of these instruments is that the file fractures are caused by combination of torsional and bending fatigue.
* The source of bending stress is the back and forth flexing of the file during use, and the cyclic torsional stresses generated during back and forth twisting from the file from the handle.
* In general, instruments used in rotary motion break in two distinct modes, torsional and flexural. Torsional fracture occurs when an instrument tip is locked in a canal while the shank continues to rotate, thereby exerting enough torque to fracture the tip. This also may occur when instrument rotation is sufficiently slowed in relation to the cross- sectional diameter29. In contrast, flexural fracture occurs when the

cyclic load leads to metal fatigue. This problem precludes the manufacture of continuously rotating stainless steel endodontic instruments, because steel develops fatal fatigue after only a few cycles. NiTi instruments can withstand several hundred flexural cycles before they fracture.

* Rotary nickel-titanium instruments with larger tapers and sizes consistently fractured after fewer rotations, and although the radius of the curves was halved, fatigue-life was reduced by 400%. The torque generated during canal preparation depends on a variety of factors, and an important one is the contact area. The size of the surface area contacted by an endodontic instrument is influenced by the instrumentation sequence or by the use of instruments with different tapers(70).A crown-down approach is recommended to reduce torsional loads (and thus the risk of fracture) by preventing a large portion of the tapered rotating instrument from engaging root dentin (known as taper lock).
* The clinician can further modify torque by varying axial pressure, because these two factors are related. In fact, a light touch is recommended for all current NiTi instruments to avoid forcing the instrument into taper lock. The same effect might occur in certain anatomic situations, such as when canals merge, dilacerate, and divide.

STANDARDIZATION OF ENDODONTIC INSTRUMENTS

Prestandardization

Before 1958,Endodontic instruments were manufactured without benefit of any established criteria.Although each manufacturers used what seemed to be unified size system,the numbering (1 through 6) was entirely arbitary.An instrument of one company rarely coincided with a comparable instrument of another company.In addition there was little uniformity in quality control or manufacture,no uniformity existed in progression from one instrument size to the next,and there was no correlation of instruments and filling material in terms of size and shape.

Beginning in 1955, a serious attempt was made to correct these abuses,and in 1959,a new line of standardized instruments and filling materials was introduced to the profession.

* A formula for the diameter and taper in each size of instrument and filling materials was proposed
* A formula for a graduated increment in size from one instrument to the next was developed
* A new instrument numbering system based on instrument metric diameter was established.

Standardization Recommended by Ingle and Levine (1958)

Ingle established a nomenclature for the basic endodontic instruments that can be used within the standardized system.

Ingle and Levine suggested a definitive increment I diameter as the size progressed while maintaining the constant taper of all blades regardless of the size

Their recommendations are:

* + 1. Instruments shall be numbered from 10-100.The number to advance by 5 units from size 10 to size 60 than by 10 units to size 100.
    2. Each number shall be representative of diameter of the instrument in hundredth of the millimeter at the tip.
    3. The working blades(flutes) shall begin at the tip designated as D1 and shall extend exactly 16mm up the shaft terminating at the designated site D2.So the length of the cutting blades (edges) is always 16mm regardless of the length of the instruments.
    4. The diameter of D2 shall be 0.32mm greater than that of D1
    5. There will be consistant increase in taper of 0.02mm/mm of every instrument regardless of the size of the instrument.

Standardization by ISO/FDI

By 1962, a working committee on standardization had been formed including manufacturers the American association of endodontists,and the American

dental association.This group evolved into the present day International standards organization (ISO).

It was not until 1976, however, that the first approved specification for root canal instruments was published (ADA sp:No: 28),18 years after Ingle and Levin first proposed standardization in 1958.

To maintain standards, the AAE urged the ADA and the United States Bureau of standards to appoint a committee for Endodontic instrument standardization. A committee was formed and after considerable work and several draft, produced a specification package that slightly modified Ingles original standardization.

In 1989, the American National Standards institute granted approval of ADA specification No:28 for files and reamers. Modifications from Ingle‟s original proposal were an additional measurement at D3, 3mm from D1, and specification for shapes of the tip: 75 degree +/- 15 degrees. The taper of the spiral section must be at a 0.02mm gain for each millimeter of cutting length. Instrument size should increase by 0.05mm at D1 between No: 10 and 60, and they should increase by 0.1mm from No: 60 to 150. In addition, instrument handles have been color coded for easier recognition.

The numbering system last revised in 2002 using number from 6 to 140 was not just arbitrary but was based on the diameter of the instrument in 100th of a millimeter at the beginning of the tip of the blades a point called D0 (Diameter 1) and extending upto the blades to the most coronal part of the cutting edge at D16 (Diameter 2) which is 16mm in length.Diameter 2 is uniformly 0.32mm greater than D1.

At the present time instruments with a taper greater than ISO 0.02mm/mm have become poular:0.04,0.06, and 0.08.This means that for every millimeter gain in length of the cutting blade,the width of the instrument increases in size by 0.04,0.06 and 0.08 0f millimeter rather than the ISO standard of 0.02mm/mm.

In contrast to the widened flare, a number of manufactures have issued half sizes in the 0.02 flare-2.5,17.5,22.5,27.5,32.5 and 37.5 to be used in shaping extremely fine canals.

The full extend of the shaft up to the handle comes in three lengths, standard 25mm,long 31mm and short 21mm.28 mm instrumented are also available72.

IMPORTANCE OF SPEED AND TORQUE

Speed:

Refers to RPM and also the surface feet per unit that the tool has with the work to be cut. Creates the speed more the cutting efficiency, however disadvantages of speed are

* Loss of factile sensation
* Loss of control
* Instrument breakage
* Change in anatomical curvature of canal Torque

Or the bending moment I used about forces that act in a rotational manner. Torque to defined by marzonk as the ability of the handpiece to withstand lateral pressure on the revolving tool without decreasing its speed ore reducing its cutting efficiency.

Importance of torque

Instrument used with high torque is very active and the incidence of instrument locking, deformation and separation tend to increase low torque would reduce cutting efficiency of the instrument and instrument progression in the canal would be difficult. The operator would then tend to force the instrument.

Both speed and torque in a handpiece can be modified by the incorporation of gear system.

Reduction gear handpieces reduce the speed of the drive whilst increasing the torque.

Torque control motors allow setting of torque generated by the motor. In low torque control, torque at deformation and at separation of rotary instruments. The motor will stop rotating and can reverse direction of rotation when instrument is subjected to torque levels equal to the torque values set on the motor.

In high torque control motors, torque values are higher compared to torque at deformation and at separation of rotary instruments. During canal preparation of the level of torque is equal or greater than the torque at deformation or at separation instrument will either deform or separate. In curved or calcified canals, resistance is high and the instrument may become blocked near the tip. High torque provided by the motor might immediately lead to fracture of the blocked instrument since the clinician has no time to stop or retract the instrument.

Ideally, NiTi rotary files should be instrumented at slow speed and ideal (right) torque. The values are usually low for smaller a less tapered instruments and high for bigger and more tapered once. To minimize risk of intracanal breakage, the instruments should be operated in a range between the martensite start clinical stress values and the martensite finish clinical stress values, which is a safe and efficient load. This means that the right torque value for each individual instrument must be calculated by the manufacturers to obtain optimum cutting performance while minimizing risks of failure.

Classification of Ni-Ti instruments-

There are basically two types of NiTi systems

1. The light speed (Light Speed, San Antonio, Texas) – A miniaturization of Gates-Glidden bur.
2. Non-light speed -
   1. Active system with a positive rake angle, that cut the dentin
   2. Passive system with negative rake angle, that mills the dentin.

CLASSIFICATION ACCORDING TO CUTTING ABILITY

|  |  |  |
| --- | --- | --- |
| Active | Semi-active | Passive |
| Protaper | Quantec | Profile |
| Hero-642  Race; Power |  | Light speed  GT |

Clifford Ruddle's classification of evolution of rotary instruments First generation (the mid to late 90s)

Rotary files with passive cutting radial lands and fixed taper such as 4% and 6% over the length of their cutting blades are included. For example, profiles

0.04 and 0.06.

Second generation (2001)

Files with active cutting edges, alternating cutting points, multiple tapers on a single file and electropolished files are included; for example: RaCe, EndoSequence and ProTaper.

Third generation (2007)

Thermally treated alloys mark this generation. These alloys exhibited superior flexibility and remarkable fatigue resistance; for example: Twisted File, HyFlex® CM, and ProfileVortex.

Fourth generation (2008)

Introduction of reciprocation concept: Endo EZE, M4, and reciprocating handpieces use equal clockwise/counterclockwise angles of 300. Yared et al. advocated unequal angles of reciprocation; For example: Wave One and

Reciproc. Self-adjusting files by ReDent Nova, with new design and mode of operation, serve as a conservative approach for root canal preparation.

Fifth generation

Files with offset designs to reduce the screwing in and breakage mark the fifth generation; for example; ProTaper Next and Revo-S.

Recently introduced NiTi file systems BT-RaCe (FKG Dentaire)-

It is a new file system introduced in 2013, derived from conventional austenite NiTi. These files have characteristic uniform triangular cross section and a blunt tip design called the booster tip. They undergo a surface electrochemical treatment that increases the resistance to cyclic fatigue

Hyflex CM (Coltène/Whaledent)-

It is a NiTi rotary system that was first manufactured in 2011, and it is the first thermo-mechanically treated NiTi endodontic alloy. NiTi files made up of CM wire do not have superelastic properties, neither at room temperature nor at body temperature in comparison to conventional NiTi files. The austenite finish temperature of Hyflex CM is 47–55°C, which is above the intracanal temperature (38). These files are reported to have a 300% times higher resistance to cyclic fatigue than conventional NiTi systems. This system tends to reduce the canal straightening effect due to its controlled memory effect.

The Hyflex EDM (Coltène-Whaledent)-

file system introduced in 2016 is considered as an evolution of the Hyflex CM, as Hyflex EDM is produced with CM alloy and uses the EDM technology. EDM is a recognized noncontact machining process that allows a precise quantity of material removed via pulsed electric discharge. Work pieces are machined in the EDM manufacturing process by generating a potential between a work piece and a tool. The sparks produced in this process cause the surface layer of the material to melt and evaporate. This creates a unique surface of new NiTi files and provides them with excellent mechanical

properties by giving the instruments a rough and hard surface and increasing their cutting efficiency.

Vortex Blue and Protaper Gold (Dentsply)

They were first introduced in 2011 as ProFile Vortex Blue. These files are manufactured through a complex heating–cooling proprietary treatment resulting in a visible titanium oxide layer on the surface, which imparts a blue colour to the alloy. They are now available as two gold and two blue heat- treated systems. Two of them are used in reciprocating motion (Reciproc Blue, VDW; WaveOne Gold), and other two are used in rotary motion (ProFile Vortex Blue; ProTaper Gold) (60). These systems can be deformed and hence also display controlled memory effect.

Max-Wire (Martensite-Austenite-electropolish-fileX)-

It is recently introduced by FKG Dentaire, is the first endodontic file system that combines both the shape memory effect and superelasticity in a single system in clinical applications. The two available marketed instruments of Max-Wire are XP-endo Shaper and XP-endo Finisher (both FKG Dentaire). These files are relatively straight in their martensitic phase at room temperature, which changes to curved shape due to phase transformation to the austenitic phase when exposed to intracanal temperature. Hence, it possesses the shape memory effect when inserted into the canal (martensite state to austenite state) and exhibits superelasticity during canal preparation.

2Shape File System (MicroMega)-

It is a new generation file system produced with a proprietary heat treatment (T-wire), which aims to enhance both the flexibility and cyclic fatigue resistance by 40% in comparison to One Shape

One Curve (MicroMega)-

It is a single file NiTi rotary system introduced in 2017, based on one single file for shaping root canal. One Curve file system is produced with a C-wire heat treatment technology. As claimed by the manufacturer, this instrument

has a controlled memory and thus the ability to pre-bend, which enhances the shaping of root canal

### Principles of chemo-mechanical preparation-65

The 2 main objectives in canal cleaning and shaping are-

1. Biological:

Biologically, the goal of intracanal procedure is to remove all pulp tissue remnants and micro-organisms and their substrates along with infected dentin.

1. Mechanical:

Mechanically 3-D shaping of the canal is the objective which must be accomplished to achieve biologic cleaning.

### Biological

* 1. Confinement of instrumentation to the roots themselves.
  2. No forcing of necrotic debris beyond the foramen.
  3. Removal of all tissue from the root canal space.
  4. Creation of sufficient space for intra-canal medicaments**.**

### Mechanical objectives according to Schielder 66

* 1. Develop a continuing tapering cone shape canal
  2. Prepare a narrower apical cros- sectional diameter within the canal
  3. Maintain the original “flow" of the canal in its multiple planes
  4. Keep the original locus of the apical foramen in relationship with the root surface and the bone
  5. Do not transport the foramen
  6. Keep the apical foramen as small as is practical

### History of root canal preparation 65

Although Fauchard in 1746, one of the founders of modern dentistry described instruments for trepanation of teeth, preparation of root canals and cauterization of pulps in his book „Le chirurgien dentiste‟, no systematic description of preparation of the root canal system could be found in the literature at that time.

In a survey of endodontic instrumentation up to 1800, Lilley concluded, that at the end of the 18th century „ only primitive hand instruments and excavators, some iron cauter instruments and only very few thin and flexible instruments for endodontic treatment had been available‟.

Indeed, Edward Maynard has been credited with the development of the first endodontic hand instruments. Notching a round wire (in the beginning watch springs, later piano wires) he created small needles for extirpation of pulp tissue.

In 1852 Arthur used small files for root canal enlargement.

Textbooks in the middle of the 19th century recommended that root canals should be enlarged with broaches: This instrument is employed to enlarge the canal, and give it a regular shape‟.

In 1885 the Gates Glidden drill and in 1915 the K-file were introduced.

In 1889 William H. Rollins developed the first endodontic handpiece for automated root canal preparation. He used specially designed needles, which were mounted into a dental handpiece with a 3601 rotation. To avoid instrument fractures rotational speed was limited to 100 r.p.m. (12). In the following years a variety of rotary systems were developed and marketed using similar principles.

The first description of the use of rotary devices seems to have been by Oltramare in 1892. He reported the use of fine needles with a rectangular cross-section, which could be mounted into a dental handpiece. These needles were passively introduced into the root canal to the apical foramen and then the rotation started. He claimed that usually the pulp stump was removed immediately from the root canal and advocated the use of only thin needles in curved root canals to avoid instrument fractures.



### Fig:75 Endodontic Beutelrock-bur in a handpiece with a flexible angle from 1912

In 1928 the „Cursor filing contra-angle‟ was developed by the Austrian company W&H (Bu¨rmoos, Austria). This handpiece created a combined rotational and vertical motion of the file.



### Fig:76 Cursor filing contra-angle

In 1957, Richman first to use ultrasonics in endodontics.

Although standardization of instruments had been proposed in 1929 by Trebitsch and again by Ingle in 1958, ISO specifications for endodontic instruments were not published before 1974.

Finally, endodontic handpieces became popular in Europe with the marketing of the Racer-handpiece (W&H) in 1958 and the Giromatic (MicroMega, Besanc¸on, France) in 1964.

Further endodontic handpieces such as the Endolift (Kerr, Karlsruhe, Germany) were marketed during this period of conventional endodontic handpieces. All these devices worked with limited, if any, rotation and/or a rigid up and down motion of the instrument, which were all made from stainless steel. The dentist could only influence the rotational speed of the handpiece and the vertical amplitude of the file movement by moving the handpiece.

A period of modified endodontic handpieces began with the introduction of the Canal Finder System (now distributed by S.E.T., Gro¨benzell, Germany) as it was 1st endodontic hand-piece with a partially flexible motion. The Excalibur handpiece (W&H) with laterally oscillating instruments or the Endoplaner (Microna, Spreitenbach, Switzerland) with an upward filing motion were further examples of handpieces with modified working motions

### CLASSIFICATION (Grossman)

The endodontic instruments can be classified on the basis of their method of use:

1. Group I: Hand-operated endodontic instruments. These include broaches, files, and reamers.
2. Group II: Non-rotary endodontic instruments used with a handpiece.
3. Group III: Rotary endodontic instruments used with a handpiece. These include low-speed instruments in which the latch type of attachment is used to retain them in the low-speed hand-pieces. Gates-Glidden drills and Peeso reamers are part of this group. This group also includes the rotary nickel titanium instruments.

### Group II:

Non-rotary Endodontic Instruments; Used with Hand pieces They can be further classified into:

Engine-driven instruments Ultrasonic and sonic instruments

### Engine-Driven Instruments:

It can be used in 3 types of contra-angled handpiece- (Ingle) Reciprocating or quarter turn handpiece

Vertical stroke along with a quarter turn motion

In addition, there are battery powered , slow speed handpieces that are combined with an apex locator, designed to prevent apical perforations.

### Reciprocating Hand piece:

1. **Giromatic (Medidenta/Micromega**)

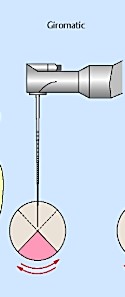
**It is** the most commonly employed engine-driven contra-angle hand piece.It accepts only latch type instruments. The Giromatic hand piece activates a stainless steel barbed broach, K-file, or K-reamer in the root canal through a 90° reciprocating arc at a speed up to 3000 cycles/min. It recommends that Rispi Sonic or Triocut instruments be used with Giromatic handpiece.

### Advantages offered by the manufacture67

It „saves worry‟ since the broach is attached to the contra-angled head there is no danger that the instrument might be dropped in the patient‟s respiratory or digestive tract.

According to Frank A El, following precautions might be taken -

* 1. Slow handpiece speed should be maintained
  2. In very narrow canals , it may be necessary to flatten the barbs of fine broach with cotton pliers.



### Fig:77 Movement of file in a giromatic handpiece

Weine *et al*. could demonstrate severe alterations in original canal shape after Giromatic preparation to ISO 25. They described the enlargement of the apical forarnen which produced a teardrop-shaped opening as the "zip." Lehman and Gerstein got only slightly more transportation and zipping with the Giromatic when used at low speed. They concluded that hand instrumentation was better and safer.

Automated devices such as the Canal Finder system or Giromatic may be used for initial enlargement of narrow and curved canals without the danger of procedural hazards such as straightening, zipping, and loss of working length. Hand instrumentation proved to be superior for the postoperative shape of the root canal. The nearly complete loss of tactile sense during the use of any automated devices should be considered additionally.68

### The M4 safety handpiece (Sybron-Kerr, USA)

It has a 30° reciprocating action. It is named so as it utilizes 4:1 gear reduction handpiece.

It is recommended to be used along with the safety Hedstrom instruments. Zakariasen *et al* found that M4, mounted with Safety Hedstrom files, to be superior to „step-back” hand preparations and a shorter time of preparation.

Results have shown that these handpieces are not effective when broaches are employed.

Care should be taken in order to avoid accidental transportation of the canal. The watch-winding, oscillating movement of this endo handpiece keeps the hand file "floating" in the canal. The operator controls coronal and apical pressures, while the M4 smoothly and efficiently "glides" the endo instrument through the canal. That's the "Safety" in the M4 Endodontic Handpiece.68



### Fig:78 M4 Safety Hand-piece

**Disadvantages-**

causes frequent breakage of instruments in the canal Creates strip perforations, ledges and zips

### Endo-Gripper (Moyco Union Broach, Montgomeryville, PA, USA )-

It has a 10:1 gear ratio and a 45 degree turning motion. It uses regular hand instruments.



### Fig:79 Endo-Gripper

1. **Endolift M4 (Sybron Endo Reciprocal rotation)**

Reciprocal rotation is 30 degree



### Fig:80 Endo-Lift M4 handpiece

**Disadvantages-**

Larger size of hand-piece can limit access in molar segments.

1. **Intra-Endo LUX 3 LD (KaVo, Biberach, Germany Reciprocal rotation)-** Reciprocal rotation 90 degree. It works with an alternating 80 horizontal rotational movement. It reciprocates at a higher speed between 30000 and 60000 reciprocations/min for greater efficiency. Intra-Endo 3-LDSY handpiece produced more straightening in the apical part of the root canal.

### Features-

14 different drill heads for all indications

Consists of configurable contra-angle handpieces composed of INTRA head and Straight & contra-angles dental handpieces. Versatile, economical, unique.

### INTRA head L68 B

Transmission ratio 1:1

Operating speed 100 - 40,000 rpm



### Fig:81 a Intrahead L68 B

1. **INTRA head L66 B**

Reduction ratio 3:1

Operating speed 35 – 13,300 rpm



### Fig:81 b Intrahead L66 B

Limitless versatility –it‟s heads are available for virtually all indications: for classical restorations, prophylaxis, endodontics, surgery.

Simply safe – all heads can be sterilised at up to 135 °C and heat-disinfected

Highly ergonomic – the particularly small heads offer an optimum view of the workspace

### Dynatrak (Dentsply DeTrey, Konstanz, Germany )

Reciprocal rotation 90 degree

### ENDOadvance -

It has a maximum speed of 40,000 rpm. It has Small head and rounded edges.



### Fig:82 ENDOadvance

4-level torque limit setting by rotary ring:

0.25 Ncm

0.5 Ncm

1.0 Ncm

3.0 Ncm

The torques indicated are reliably maintained and not exceeded. If the set torque is reached, the safety clutch slips and the file stops rotating immediately. We can hear and feel the response of the safety clutch.

### VDW Connect drive-

It is a wireless device. It generates reciprocating working motion and full clockwise rotation. It can be connected via Bluetooth. A special app offers the opportunity to select the required working motion, either reciprocating or full clockwise rotation. Additional function such as electronic apex locator can be selected via app.

### Fig:83 VDW Connect drive

**Reciprocating files-**

Reciprocation extends the lifespan of all types of files tested. Reciprocating and rotary motion have similar cutting efficiency.

Reciprocating files shape canals well and preserve the original canal anatomy.

RFs can promote significant bacterial reduction, but like rotary full sequence systems, they are not able to completely disinfect the RCS.

The ability of RFs to extrude less debris than rotary files remains a matter of debate.

### Vertical Stroke Handpiece:

This is an air or electrically driven hand piece that employs a vertical stroke varying between 0.3 and 1 mm.

The handpiece also delivers a quarter-turn reciprocating action when the instrument starts to bind with the canal wall.

### Canal Finder System (Societe Endo Technique, Marseille, France)

It was developed by Levy in 1984 and represented the first endodontic handpiece with partially flexible motion.69

The handpiece has a variable up and down motion with an amplitude between

0.3 and 1 mm depending on the motor speed. An additional turning motion starts when the instrument encounters friction in the root canal. The system was used with special SET-K-files (ISO 15-20) and SET-Hedstroem files (ISO 15-30).70

The amplitude of the vertical file motion depended on the rotary speed and the resistance of the file inside the root canal and changed into a 90 degree rotational motion with increasing resistance.



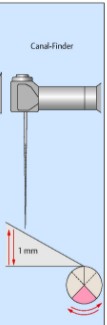
### Fig:84 a Canal Finder system

It operates from the turbine air supply in a vertical motion. It has a continuous water-irrigant and coolant feature that helps maintain canal patency. The amplitude of the vertical file motion depended on the rotary speed and the resistance of the file inside the root canal and changed into a 90 degree rotational motion with increasing resistance. It was an attempt to make the root canal anatomy or at least the root canal diameter one main influencing factor on the behaviour of the instrument inside the canal.

The effectiveness of this device was evaluated comparing the original and post-instrumentation shapes of the root canal system (Goldman et al. 1987, Goldman *et al*. 1989, Campos & Del Rio 1990). They found that the Canal Finder performed better than or equal to hand instrumentation.

It was later used with integrated permanent irrigation (ie Sodium hypochlorite) and electrical control of working length, features also found in modern endodontic system.69

The vertical movement of the file will also help to bypass an instrument fragment. The flutes of the file can mechanically engage with the separated instrument, and with the vertical vibration the instrument fragment can be loosened or even retrieved. It should be used cautiously to avoid root- perforation in curved canal. These are technique sensitive and thus results can vary in between the cases.68

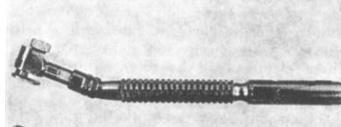


### Fig:84 b Flexible vertical movement plus friction dependent free reciprocal rotary motion

The Canal Finder system has been reported by Tronstad and Niemczyk to be a safe device for preparation with good ability to maintain the original canal shape. Other investigations (Hulsman, Tronstad, M.Stryga) have shown adverse results, especially many cases of zipping.68

### Racer (Cardex, via W&H, Bu¨rmoos, Austria)69

It was released in 1958, with an amplitude of 1 to 2 mm vertically.



### Fig:85 a Racer handpiece

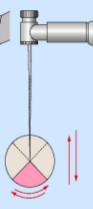


**Fig:85 b vertical oscillations (Racer)**

### Endolift (Kerr, Karlsruhe, Germany)-

The Endolifl handpiece makes an up and down movement with an additional

90 ° turning motion( vertical + Reciprocal motion ). It was used with conventional reamers and Hedstroem files (VDW, Mtinchen, Germany) (ISO 15-30) inserted.70



### Fig:86 Rigid vertical movement plus simultaneous reciprocal motion

It cuts best when the entire pulp chamber is flooded with sodium hypochlorite. The instrument appeared to follow the canal adequately, but it is very time- consuming. The over-all head and instrument size make it difficult to operate in the second molar area.

It should be used in slow-speed. Endolift has been shown to produce more alterations than hand instrumentation in apical root canal morphology by Lehman and Gerstein and H~ilsmann and Bertzbach.68

### Endoplaner (Microna, Spreitenbach, Switzerland) –

The handpiece makes an upward scraping movement when pressed against the root canal wall. The handpiece was used with specially designed K-soft- files (ISO 15-20) and Hedstroem files (ISO 15- 30).

1. **Canal Leader 2000 (Systemvertrieb EndoTechnik, Olching, Germany)** It works with a vertical movement of I mm amplitude and an additional turning motion. It is a speed reducing hand-piece with 4:1 step-down. Specially designed Universa lfiles (ISO 15-30) are used for preparation.71



### Fig:87 Canal Leader 2000

1. **EndoEZE AET (ultradent)-**

It is a more recently introduced handpiece for preparation of canals with oval cross sections. The Endo-Eze EVOS contra-angle is an 8:1 reduction, stainless steel contra-angle intended for use during endodontic treatment. The EVOS contra-angle can rotate in both rotary and reciprocation mode, depending on the motor settings.



### Fig 88 EndoEZE AET

The EVOS contra-angle can be used with the EVOS motor and Genius files, but is also compatible with other endodontic systems.

### Ultrasonic and Sonic hand-pieces

Richman was the 1st to report on using ultrasonics in endodontics in 1957.Martin and Cunningham did a series of experiment from 1976-1982 on ultrasound and it‟s application in endodontics which led to the production of Cavi-Endo system in 1982. However, it was not until Martin et al. demonstrated the ability of ultrasonically activated K-type files to cut dentin that this application found common use in the preparation of root canals before filling and obturation. The term “endosonics” was coined by Martin and Cunningham and was defined as the ultrasonic and synergistic system of root canal instrumentation and disinfection.

### Mechanism-

Ultrasound is sound energy with a frequency above the range of human hearing, which is 20 kHz. The range of frequencies employed in the original ultrasonic units was between 25 and 40 kHz. Subsequently the so-called low- frequency ultrasonic handpieces operating from 1 to 8 kHz were developed, which produce lower shear stresses, thus causing less alteration to the tooth surface.

There are two basic methods for producing ultrasound.

* 1. magnetostriction that converts electromagnetic energy into mechanical energy. Various strips of magnetostrictive metal in a hand-held piece are joined to a stable, alternating magnetic field producing vibrations as a result.
  2. The second method, based on the piezoelectric principle, uses a crystal which changes size when an electrical charge is applied. When the crystal deforms, it goes into mechanical oscillation without producing heat.

Magnetostrictive units create figures of eight (elliptical movement), which is not ideal for endodontic use and another drawback with these units is that heat is generated, so adequate cooling is required.

Piezoelectric units have some advantages over magnetostrictive units as they produce more cycles per second, 40 as against 24 kHz. The tips of these

units work in a linear movement from back to front like a piston which is ideal for endodontic treatment.72

One of the most important advantages of ultrasonic tips is that they do not rotate, thereby delivering safety and control while maintaining high cutting efficacy.

### Action of ultrasonics and sonics in cleaning and shaping-

This is accomplished by different ways. One is by vibratory motion of the instrument which when moved up and down in the root canal will abrade the root canal walls. Cavitation and acoustic streaming are other properties. Acoustic streaming is responsible for the debriding action. Acoustic streaming

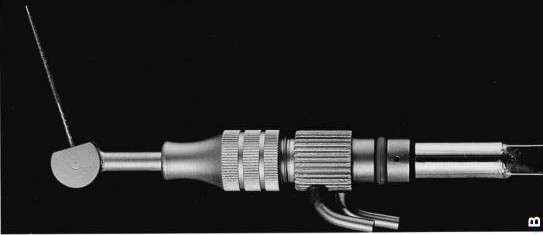
„depends on free displacement amplitude of the file‟ and that the vibrating file is dampened in its action by the restraining walls of the canal.69

### Various ultrasonic handpieces-

1. **Cavi-Endo (L.D.Caulk Division of Dentsply Intl) and Enac ( Osada Electric Co. Inc.Los Angeles)**

It uses ultrasonic energy to enlarge root canal. Ultrasonic energy is utilized to clean and shape root canals, remove debris and disinfect all in one operation. These instruments all deliver an irrigant/coolant, usually sodium hypochlorite, into the canal space while cleaning and shaping are carried out by a vibrating K file.

CaviEndo represents a magnetostrictive driven ultrasonic unit 25 000 Hertz. Cavitation does not occur in caviEndo.



### Fig:89 ACaviEndo unit with handpiece (right) and reservoir hatch (top right). Dials (front panel) regulate vibratory settings. Foot control not shown. B, CaviEndo handpiece mounted with an Endosonic diamond file. Irrigating solution emits through a jet in the head. (Courtesy of Dentsply/Cavitron.)

Enac represents a Piezoceramic driven ultrasonic unit 30 000 Hz. Cavitation occurs in Enac. According to Ahmed and Pitt, Enac unit had a greater prospensity for producing elbows as well as apical deviation.69

### Piezon Master 700 (Electro Medical Systems, Le Sentier, Switzerland) -

**It** represents a piezoceramic driven ultrasonic unit (25.-32.000 Hertz). It has two different modalities: the „Standard‟ ultrasonic mode and the „Endo‟ mode. The „Endo‟ setting has been specifically designed for deep cavity endodontics as it reduces the power curve to deliver a more delicate treatment. The device also has the ability to switch between liquid containers, allowing for the use of different solutions throughout a therapy without ever having to change bottles.



### Fig:90 Piezon Master 700 (Electro Medical Systems, Le Sentier, Switzerland

**Effects of ultrasonics on Shaping of root-canal-72**

Most studies report unsatisfactory results concerning the quality of preparation, due to the high-frequency oscillations resulting in poor control of the file and especially the file tip. Since ultrasonic units are used with stainless steel instruments, the outer aspect of curved root canals is easily straightened or shows severe zipping and ledging. Longitudinal grooves in the root dentin following the use of ultrasonically activated files have been detected. When used carefully, ultrasonic instruments can be helpful in removal of obstacles, opening root canal orifices, and widening narrow isthmi.

Nevertheless, other studies have failed to demonstrate the superiority of UI as a primary cleaning and shaping technique. These results might be attributed to the constraint of vibratory motion and cleaning efficacy of an ultrasonic file within the nonflared root canal space. In addition, it is difficult to control the cutting of dentin during UI and hence the shape of the prepared root canal. Strip perforations as well as highly irregular-shaped canals were frequently produced. Therefore, UI is not generally perceived as an alternative to conventional hand instrumentation. On the contrary, the endodontic literature supports that it is more advantageous to apply ultrasonics after completion of canal preparation.

### Effect of ultrasonics on Cleaning of root-canal-73

The cleaning and disinfecting capacity of ultrasonics is still controversial. Excellent or good root canal cleanliness, removal of debris and smear layer compared to conventional irrigation techniques have been reported.

### Advantages of ultrasonics-73

* Researchers have not addressed common problems such as ledging, apical zipping, and strip perforations. This is because ultrasonic endodontics does not involve twisting or turning instruments.
* Reduced operator fatigue
* Less traumatic procedure
* Chen ail and Teplitsky (1985) Studied changes in canal curvatures before and after ultrasonic instrumentation, they found that no measurable alterations occurred in 94% of the canal. Ultrasonic instrumentation produced irregularly shaped canals in the middle and coronal third. According to a study by Cimmermann *et al*, ultrasonic instrumentation appears to be efficient and safe for shaping curved canals.

### Sonic handpieces

**It** operates at 1.5-3 kHz when used inside root canals. They are similar in shape and weight to dental handpieces and are attached to existing air and water lines. These instruments are used in a manner similar to the ultrasonic system in instrumentation of the root canals.

Tronstad *et al* were the first to report the use of a sonic instrument for endodontics in 1985.

### MECHANISM-

Sonic irrigation is different from ultrasonic irrigation in that it operates at a lower frequency (1–6 kHz) and produces smaller shear stresses. The sonic energy also generates significantly higher amplitude or greater back-and-forth tip movement.

Moreover, the oscillating patterns of the sonic devices are different compared with ultrasonically driven instruments. A minimum oscillation of the amplitude might be considered a node, whereas a maximum oscillation of the amplitude represents an antinode. They have 1 node near the attachment of the file and 1 antinode at the tip of the file (86). When the movement of the sonic file is constrained, the sideway oscillation disappears. This results in a pure longitudinal file oscillation. This mode of vibration has been shown to be particularly efficient for root canal debridement, because it is largely unaffected by loading and exhibits large displacement amplitudes.

The sonic file oscillates in a large elliptical motion at the tip out in the open. However, when loaded, as in a canal, the motion changed to a longitudinal one, up and down. 73

### Various Sonic hand-pieces-

* 1. **MicroMega 1400 Sonic Air Endo system (Medidenta/MicroMega, Woodside,NY handpiece**)69

It attaches to the regular airline at a pressure of 0.4 Mpa. It has an oscillatory range of 1500 to 3000 cycles per second. Tap water irrigant/ coolant is delivered through the handpiece to the preparation.



### Fig:91 a MicroMega 1400 Sonic Air Endo system

It employs 3 endodontic instruments -RispiSonic and ShaperSonic, and the Trio Sonic (Medidenta International, Inc.)-

1. The Rispi Sonic resembles the old rat-tail file. The Rispisonic files have a nonuniform taper that increases with file size. Because they are barbed, these files might inadvertently engage the canal wall and

damage the finished canal preparation during agitation. The Rispi-

Sonic® files are stainless steel and have barbs along the length of the fi le in a spiral design . This fi le is designed to cut dentin as well as agitate the irrigant solution with the canal. Irrigant is delivered and refreshed intermittently via needle delivery and not by the handpiece.it has 8 cutting blades.

1. The Shaper Sonic resembles a barbed broach. It has 16 cutting blades.
2. The Trio Sonic resembles a triple-helix Hedstroem file.



### Fig:91 b A.RispiSonic B. Shaper Sonic C. Trio sonic

The ISO sizes range from 15 to 40. These instruments must be free to oscillate in the canal and to rasp away at the walls and it gets easily adjusted to the length of the tooth. The sonic system has been shown to extrude the least amount of material out the apex. The sonic instruments are primarily for step-down enlarging, not penetration. Goldman *et al*. tested sonic versus ultrasonic units and concluded that they were all effective in canal preparation but judged the Micro Mega Sonic Air System, using Rispi and Shaper Sonic files, „„as the best system tested.‟‟

### The Mecasonic unit

It is a sonic system with an oscillation of 1500 to 3000 Hz. It was used with Meca-Shaper instruments.

### Advantages of Sonic

* Better shaping of canal as compared to ultrasonic preparation
* Due to constant irrigation, lesser chances of debris extru sion beyond the apex
* Produces clean canals free of smear layer and debris

### Disadvantages of sonic

* Walls of prepared canals are rough
* Chances of transportation are more in curved canals.

### Ultrasonic VS Sonic instrumentation-

The results of the various studies can be summarized as being contradictory. They failed to demonstrate the superiority of US or sonics as a primary instrumentation technique, as no improved debridement was accomplished compared with hand instrumentation. The relative inefficiency of ultrasonic debridement has been attributed to file constraint within the unflared root canal space.

A modification of the technique in which ultrasound is activated for a few minutes after hand preparation has instead resulted in greater canal and isthmus cleanliness compared with hand preparation alone. Despite the multitude of studies conducted on ultrasonic root canal preparation with ultrasonically activated files, the current consensus is that this is not a viable clinical technique. 69,72

### Group III: Rotary Endodontic Instruments Used with a specific Handpiece Rotary handpiece:

* These handpieces work at speeds ranging 150-300rpm upto 1500rpm, achieved with gear reduction (1:8 or 1:10).
* Higher speed is occasionally advocated for better efficacy and safety however lower speeds offer better compromise regarding fatigue lifespan and occurrence of taper lock.
* Electric motors offer several benefits like potential to present rotations per minute, preselect maximum torque to prevent instrument fracture.
* Various settings are possible for some torque-limited motors; the motor can stop, go into reverse or into oscillations.
* Ergonomic friendly

### Motors-

Motors for rotary instruments have become more sophisticated since the simple electric motors of the first generation in the early 1990s.

Examples of motors used with rotary nickel-titanium endodontic instruments-

1. 1st generation motors- without torque control
2. Second-generation motor -Fully electronically controlled with sensitive torque limiter.
3. 3rd generation- simple torque-controlled motor.
4. Newer generation motor with built-in apex locator and torque control.

### Fig:92 Motors used with rotary nickel-titanium endodontic instruments

**a. 1st generation motors b.2nd generation c. simple torque controlled motors d. newer generation motors**

Electric motors with gear reduction are most suitable for rotary NiTi systems, because they ensure a constant rpm level and constant torque. They can also be programmed to provide alternative rotation patterns, for example, reciprocation with freely selectable angles of rotation.

Electric motors often have presets for rpm and torque and are capable of delivering torques much higher than those required to break tips. Some authors think that torque-controlled motors increase operational safety. Others have suggested that such motors may mainly benefit inexperienced clinicians. These motors probably do not reduce the risk of fracture caused by cyclic fatigue, and even if the torque is below the fracture load at D3, a fracture at a smaller diameter (D2) is still possible

Earlier concepts preferring high-torque motors were followed by development of low-torque motors, some of which have several special features as auto start/stop, auto apical reverse in combination with an electronic device for determination of working length, auto torque stop, auto torque reverse, handpiece calibration, twisting motion and programmed file sequences for primary preparation and retreatment.

Initially, high-torque motors were preferred in order to allow efficient cutting of dentine and to prevent locking of the instrument. However, the incidence of instrument fractures was relatively high with these motors.

The rationale for the use of low-torque or controlled-torque motors with individually adjusted torque limits for each individual file is to keep the instrument working below the limit of instrument elasticity without exceeding the instrument-specific torque limit thus reducing the risk of instrument fracture . The values should range between the martensitic start clinical stress and the martensitic finish clinical stress, which is dependent on design and taper of the individual instrument. On the other hand, current norms stipulate the measurement of torque at failure at D3, a distance of 3 mm from the tip of the instrument. For an instrument with a taper of 0.06 and larger, it becomes difficult to determine a torque that is sufficient to rotate the larger more coronal part of the instrument efficiently while not endangering the more fragile apical part. In fact, it has been suggested repeatedly that the creation of a glide path allows the apical end of the instrument to act as a passive pilot and thus protects the instrument from breakage even with high torque.74

### Motors with constant speed and constant torque-75

Initially, NiTi instruments were used in regular low speed dental handpieces, which resulted in a clinically unacceptable number of instrument fractures. In consequence, special motors with constant speed and constant torque were introduced for use with these instruments

### Table-4. Endodontic motors for root canal preparation using Ni-Ti instruments

**MOTORS AND TORQUE CONTROLLED HANDPIECES**

### Importance of Torque -during Cleaning and Shaping

Recently, a generation of low and very low torque control motors has been introduced. Torque values as low as 1 N/cm2 can be set on these torque control motors, these motors take into consideration and low torque at failure values of rotary instruments. If the high torque is used the instrument-specific torque limit is often exceeded, increasing the mechanical stress and the risk of fractures, thus it must be emphasized that the elastic limit of the tested instrument is found to be lower than 1 N/cm2 when subjected to torsional testing.

Theoretically, an instrument used with a high torque is very active and the incidence of instrument locking and consequently deformation and separation would tend to increase, whereas a low torque would reduce the cutting

efficiency of the instrument, and instrument progression in the canal would be difficult. The operator would then tend to force the instrument and may encourage instrument locking, deformation, and separation. A low torque motor should be used to limit this potential breakage, if the torque is set just below the limit of elasticity for each instrument, the mechanical stress is lower, the risk of deformation and separation is likely to be reduced.

Theoretically, with low torque control motors, the motor will stop rotating and can even reverse the direction of rotation when the instrument is subjected to torque levels equal to the torque values set on the motor. Thus, instrument failure could be avoided Gambarini, in 2001, and Berutti *et al*., in 2004, stated that endodontic motors with lower torque values cause lower cyclic fatigue in NiTi rotary instruments.74,75

### Slow speed, low-torque (right-torque) motors76

ROLE OF MOTOR

Torque control motors allow the setting of torque generated by the motor. In low torque control motors, torque values set on the motor are supposed to be less than the value of torque at deformation and at separation of the rotary instruments. Where as in high torque control motors, the torque values are relatively high compared to the torque at deformation and at separation of the rotary instruments.

In curved and/or calcified canals the resistance is high and the instrument may become blocked near the tip. In these situations, the high torque provided by the motor might immediately lead to fracture of the blocked instrument, especially since the clinician usually has no time to stop or retract the instrument

### Disadvantages of low-torque motors

use of low-torque motors is likely to change tactile and mental awareness, but operative sequences as well, because cutting efficiency is reduced

Whereas with low torque, the cutting efficiency would be reduced and instrument progression in the canal would be more difficult

### NSK Endo-Mate Endomotor –

The Nippon Seiko Kabushiki-gaisha Limited (NSK Ltd.) company began it‟s production of metal bearings back in 1914. They have come up with 3 endo motors namely the Endo Mate AT, TC2 and DT. The best seller among these is the NSK Endo Mate DT. All contra angle heads are autoclavable up to 135°C

### Endo Mate AT-

The endodontic motor has a wide range of torque and speed settings, allowing it to be used with Ni-Ti Files from virtually all major manufacturers.



### Fig:93 Endo Mate AT

**Features-**

* + - Fits all major brands of Files Torque control
    - with integrated auto-reverse function -The auto reverse function activates when the preset torque level has been exceeded and can be set to operate in the following
    - monitor pad Large screen size for immediate visibility Flat control panel for simple and user-friendly operation Lightweight,
    - Smart handpiece offering excellent visibility
    - 9 preset settings (speed and torque etc) are available and can be programmed simply by pushing the memory function button. Moving between each preset program is easy and allows application of the handpiece with all major Ni-Ti File manufacturer's required settings.
    - Max Torque - 7 Ncm (when using 20:1 head)
    - Speed range- 100~13,000 min-1

### Endo Mate TC2-

A large LCD, simple 5-key operation and a lightweight, cordless handpiece assure easy use even during the most delicate endodontic procedures.

The Auto Reverse & Alarm Function alerts you with an audible sound to let you know that the load is about to reach the preset torque level allowing you to unload the file even before the Auto Reverse is setting in.

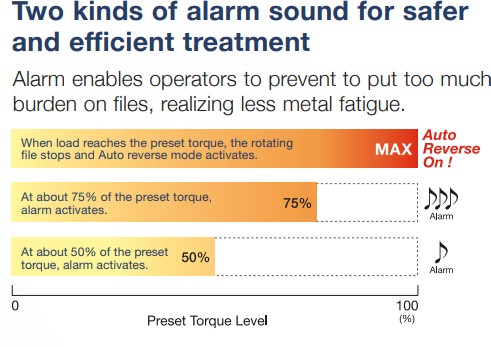
5 programs for different file systems. It supports most major brands of Ni-Ti files.



### Fig:94 a Endo Mate TC2

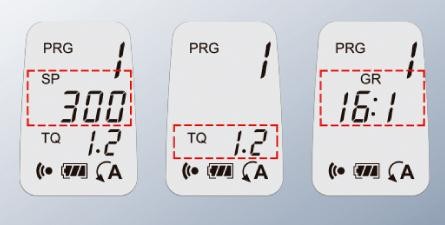
**Features-**

* The feedback circuit keeps stable rotation even when the load on the motor handpiece changes
* Power turns off automatically to improve safety and save energy
* Calibration function for more precise rotation speed and torque setting

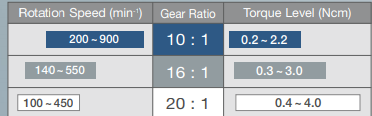


### Smart Auto Reverse & Alarm Function for safer endodontic procedures

User definable 5 presets – Speed, Torque, Gear Ratio & Auto Reverse mode. Last program settings can be memorized when the power turns on.



Selecting gear ratio attachment applies the entire rotation and torque.



The heads are equipped with built in probe ring which enable to use Apex locator with the ENDO-MATE TC2 system. By combining an Apex Locator with NSK ENDO-MATE TC2, clinicians will be able to perform more accurate root canal preparations.



### Fig:94 b head of Endomate TC2

* 1. **Endo-mate DT-**

This endo motor has been developed for use with most of the major brands of NiTi rotary files. There are pre-programming functions to memorize the exact speed and torque settings for up to 9 NiTi file systems from all major manufacturers. There are 3 auto reverse functions namely – autoreverse on, auto-stop and auto-reverse off, which react when the load reaches the present torque level.

The handpiece has an on/off switch to offer pedal free operation. However, an optional foot control pedal can be used along with the Endo Mate DT endo motor. This endo motor has a 2-way power source. It can work with a rechargeable battery (DC) to facilitate portable use or it can be powered using the AC adaptor that is supplied along with the kit.

It has a speed range of 100 – 13,000 rpm and has a maximum torque level of 7 Ncm.



### Fig:95 Endo Mate DT

1. **Dentsply X Smart-**

The endodontic micromotor is designed specifically to drive NiTi rotary instruments. X Smart can operate on battery or electrical power. The battery recharge time is about 5 hours and the use time is 2 hours approximately.



### Fig:96 Dentsyply X-Smart

The clear LCD screen on the device is angled for easier visualization during the endodontic procedure.

Having a total of 9 memory programs it allows the clinician to change parameters such as speed, torque, gear ratio, the direction of rotation and others. The graduated bar shows a real-time readout of the load that is applied to the rotary instrument.

X Smart does not feature the reciprocating function and allows only continuous rotational motion of the rotary files. The device also has battery charge indicator and audible warning signals. The endomotor has a speed and torque range of 120 – 800 rpm and 0.6 – 5.2 Ncm respectively**.**

### A. Dentsply X-Smart Plus Endomotor-

* Miniature contra-angle head that can be adjusted in 6 positions
* On / Off button on the motor hand piece- No foot pedal

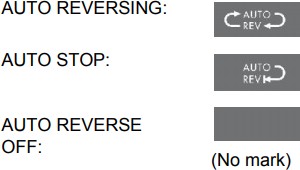


### Fig:97 Dentsply X-Smart Plus Endomotor

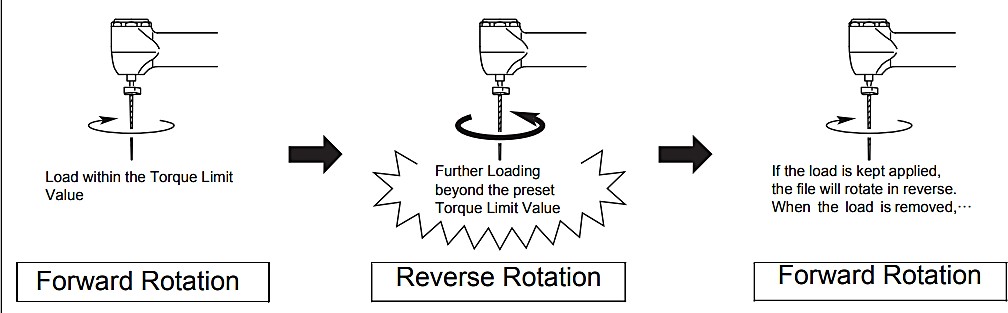
* It has both Reciprocating motion and continuous rotation
* Includes a file library with pre-set programs for

1. Continuous rotary systems • Gates • Proglider® • PathFile® • Protaper Next® • ProtaperGold® • Protaper® Universal • Program (individual programs)
2. Reciprocating systems • WaveOne® Gold • WaveOne® • RECIPROC® ALL (RECIPROC® and RECIPROC® blue)

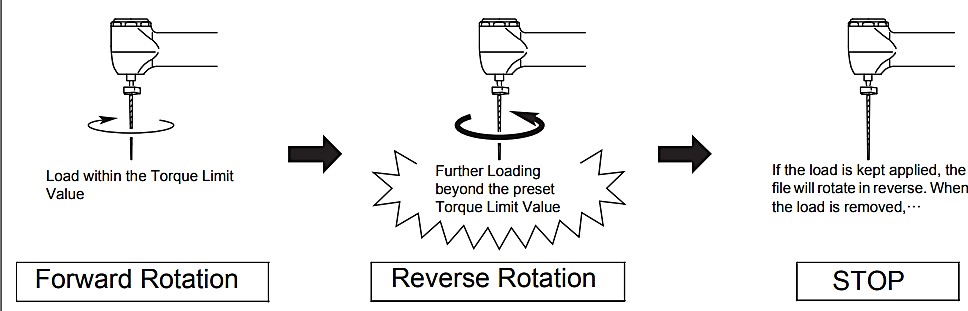
* 6 free programs for individual settings in continuous rotation
* Auto reverse rotation at pre-set torque limit
* Torque range: 0.6 – 4.0 Ncm
* Speed range: 250 – 1‟200 rpm
* Operates on a rechargeable battery and when connected to the mains Auto Reverse Function There are 3 different auto reverse modes:



1. AUTO REVERSING: If, during operation the load reaches the preset torque limit value, the motor handpiece will automatically rotate in the reverse direction. When the load is removed, the motor handpiece returns to normal forward rotation automatically.



1. AUTO STOP: If, during operation the load reaches the preset torque limit value, the motor handpiece will automatically rotate in the reverse direction. When the load is removed, the motor handpiece stops. The LCD panel shows " " and the rotation speed alternately.If you want the file to rotate forward again, press the ON/OFF key twice.



1. AUTO REVERSE OFF: If, during operation the load reaches the preset torque limit value, the motor handpiece will stop without reverse rotation. The LCD panel shows " " and the rotation speed alternately. If you want the file to rotate forward again, press the ON/OFF key twice.

### Endo Radar EndoMotor (Guilin Woodpecker Medical Instrument Co., Ltd. )-

Wireless endo motor covers apex locator.



### Fig:98 Endo Radar EndoMotor (Guilin Woodpecker Medical Instrument Co., Ltd. )

**Continuous mode-**

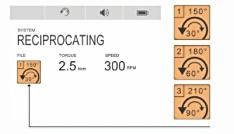
Three automatic reverse functions, avoiding instrument fractures result from improper force exertion in manual operation. When reaching the preset torque, automatically reversely rotate; it will back to forward rotation after disappearance of resistance. When reaching the preset torque, automatically reversely rotate; it will automatically stop after disappearance of resistance. Automatically stop when reaching preset torque.

Speed 100-65 RPM

Torque 0.6-4.IN cm

### Reciprocating mode-

Be compatible with all popular single file systems on the market. Accurate angle control; three optional reciprocating angles.



### Program mode-

Eight optional self-define modes which can be automatically stored after setting.

**There are 3 modes**- auto reversing, auto stop, auto-reverse off. Push the handpiece button twice to restart the handpiece.

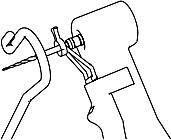
The display of the torque Instructions -

* 1. when it shows location 1 in the picture, The current load is 50% of the preset load
  2. when it shows location 2 in the picture, The current load is 80% of the preset load
  3. when it shows location 2 in the picture, The current load is 100% of the preset load and the motor stops.

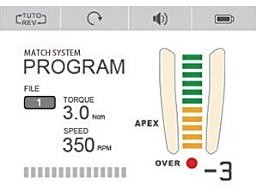


### Combined length determination mode

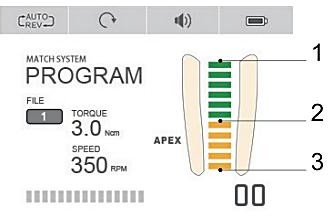
1. **Base setting**
   1. Touch the “En-Ap” button to select the Combined length determination mode.
   2. Select file system.
   3. Combined length determination mode parameter setting



1. **Connection testing(Test every time before using)**: touch the file with the lip hook, if it show”-3”, it works well, otherwise, the USB wire or measuring wire should be replace.



1. Hook the lip hook in the corner of the patient‟s mouth.
2. Power on the motor handpiece to operate.
3. The display of root hole magnified area display in combined length determination mode:



### Care-

1. Approx 2mm to apical foramen
2. Approx 0.6mm to apical foramen 3 Apex(apical foramen)

Do not sterilize. After each use, all the objects that were in contact with infectious agents should be cleaned using towels impregnated with a

disinfecting and detergent solution (a bactericidal, fungicidal and aldehyde free solution) .

### Endo Smart

It Adopt real-time feedback technology and dynamic torque control, effectively preventing needle breakage. It has Wireless handpiece which enables more convenient operation. Wireless charging avoids poor contact problem of traditional contact charging. Storage of 9 user-defined modes allows invocation at any time. Under each mode, Continuous Rotation Mode, Reciprocating Motion Mode, and Reverse Rotation Mode are for options.

15.5:1 reduction ratio endows strong power and efficient cutting



### Fig:99 Endo Smart handpiece

It has Automatic torque calibrating- choose torque calibrating mode to automatically calibrate torque, reducing the torque fluctuation caused by contra angle replacement or sterilization under high temperature and high pressure.

Contra-angle can be autoclaved and is adjustable to make it available for different teeth positions.

Torque: 0.6Ncm-5.0Ncm(6mNm ~ 50mNm) Rotate speed: 100rpm~1000rpm

### Ai-Motor

Features:

* 1. Efficient brushless motor, low noise, long service life.
  2. Cordless portable endo motor with combined length determination.
  3. 360 degrees rotation of contra angle- adjustable reciprocating angle (10degree interval, adjustment range-20 degree-340 degree). Accurate rotating angle reduces risk of instrument fracture and enables higher preparing efficiency.
  4. dynamic torque control, effectively preventing file separation.
  5. small head design, brings clear vision during operation



**Fig:100 Ai-Motor** Torque range: 0.4Ncm-5.0Ncm（4mNm ~ 50mNm） Speed range: 100rpm~1200rpm

### SAESHIN ENDO CUBE

Endo Cube by Saeshin has been a reliable endomotor for many dentists for a considerable amount of time. There are 9 programmable memory functions for gear ratio, torque, speed, rotating direction and others.

The endo motor has an automatic overload protection function that protects the endodontic file when the torque value exceeds the setting value. It also

features an automatic power off function that switches the device off after 10 minutes of inactivity and this is indicated by a beep sound. This feature aids in saving battery life of the end motor.

The speed and torque of the endo motor range between 100 – 800 rpm and up to 5.2 Ncm respectively.



### Fig:101 SAESHIN ENDO CUBE

1. **E Connect Pro Endo motor**

E Connect Pro has a cordless design with 3 buttons to set the various parameters. A very functional improvement is the fact that the contra-angle head can be rotated around 340 degrees. This facilitates easier operation while working on multiple quadrants of the oral cavity. The dentist can simply rotate the head to have a view of the LCD display. It has programmable functions for speed and torque and also for continuous rotation and reciprocation.



### Fig:102 E Connect Pro Endo motor

A striking innovative feature is the ability to use regular rotary files such as the Neoendo Flex Files in Reciprocatory Motion. This gives the dentist the flexibility to use reciprocating motion in certain situations and increase the lifespan of the endodontic files. The other features of movement include continuous forward rotation, continuous reverse rotation, reciprocation and torque reversal.

The E Connect Pro can be integrated with the E Pex Pro Apex Locator to take complete control of BMP. The connecting cord enables real-time visibility of the position of the tip of the file in the canal.

When connected to the apex locator the E Connect Pro offers the following useful functions:

1. Auto Start/Stop-The motor starts when the file enters the canal and stops when the file is withdrawn.
2. Apical Reverse- When the file reaches the pre-set apical reverse point, it begins reverse rotation (user-defined).
3. Apical Slow Down-To preserve the CDJ and avoid file separation, the motor slows down when the file reaches the apical third of the root canal.
4. d. Apical Torque Reduction: When the file reaches the apical third of the root canal the torque is also reduced to reduce the chances of file separation.

### Marathon A Class Endo Motor

The A Class endomotor by Saeyang Marathon is among the most sought after endomotors of today. It is a cordless system eliminating the presence of a wire connecting the handpiece to the control unit. This greatly enhances ergonomics and comfort for the dentist. The endo motor consists of the new age Reciprocating System which has two modes – Forward Reciprocating and Reverse Reciprocating, in addition to the conventional continuous rotation motion.

The device contains 6 memory programs namely – Mode ( Auto Stop Reverse, Reverse, Auto Stop Manual), Gear Ratio, Torque and Speed. The auto reverse function of the endomotor reduces the load on the rotary file when the torque has exceeded the specified limit. When the level of torque increases beyond the set limit the endo motor stops running immediately and starts to run in the reverse direction. Once the load is removed the motor drives the file in the forward direction. The following table shows the some of the compatible gear ratios with their corresponding speed and torque ranges:



The A Class endomotor features a NiMH battery that offers a use time of 90 minutes. The charging unit draws 11VA of power and acts as the holder for the endo motor as well.

### Root ZX II OTR Module

OTR stands for (Optimum Torque Reverse). The Root ZX II Low Speed Handpiece with OTR technology prepares root canals while displaying precise and accurate measurements. With a revolutionary file advancement feature, OTR reduces file fatigue, as well as the possibility of file breakage. Lightweight, the handpiece is ergonomically designed to minimize fatigue and fingertip stress and is ideal for endodontic access.

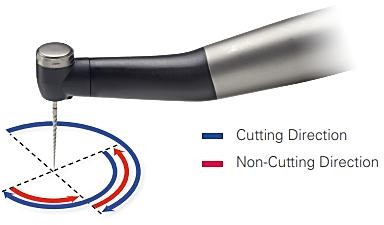


### Fig:103 Root ZX II OTR Module

**HOW IT WORKS-**

During file rotation, the torque is automatically measured. If the torque is less than the set value, the file rotation continues, but if the torque has reached the set value, the file reverses rotation by 90° and then continues in the cutting direction once again. files that cut in the forward rotation must be used. OTR reduces file fatigue, as well as the possibility of file breakage. Lightweight, the handpiece is ergonomically designed to minimize fatigue and fingertip stress and is ideal for endodontic access. It offers 3 speed settings of 100, 300 and

500 rpm and 3 programmable memory modes. The module also offers operation in Normal Mode without the Optimum Torque Reverse function. In Normal Mode, 8 speed settings from 150 rpm to 800 rpm and 11 torque settings are available. This mode is useful for opening the upper part of the canal.



### FEATURES AT A GLANCE-

Safely & efficiently clean & enlarge canals with OTR technology Standard Ni-Ti file can be used – no need for special files

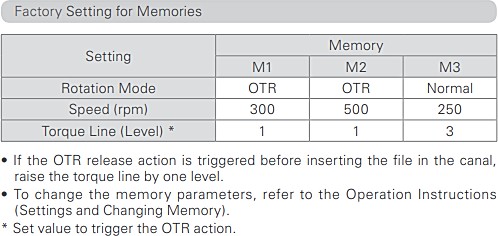
New contra head has internal file electrode

OTR Module can be connected to any Root ZX II 6 Automatic Safety Features

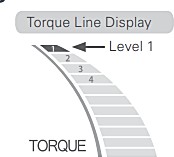
1. OTR Technology -When the torque setting is reached, the file auto reverses 90° then continues again in the cutting direction. OTR reduces file fatigue, as well as the possibility of file breakage.
2. Auto Motor Start/Stop No foot switch required. Motor starts when file is inserted into the canal and stops when it is withdrawn.
3. Auto Torque Reverse Reduced file breakage. File stops and reverses if the torque goes over the set torque limit. There are 11 torque settings.
4. Auto Torque Slow Down Reduced file breakage. File slows down as the torque approaches the set torque limit.
5. Auto Apical Reverse File stops and reverses when it reaches the end of the set working length.
6. Auto Apical Slow Down File slows down as it approaches the end of the set working length, ensuring safe and accurate preparations.

### USAGE-

1. Press the power button to turn on the unit
2. Memory selection- OTR MODE

Press the button to set the memory to the OTR mode, You may select either M1 or M2 for the file's appropriate rotation speed.

1. Check Torque Bar Reading- The torque line should be set at 1 and the file used with a vertical motion (pecking motion).

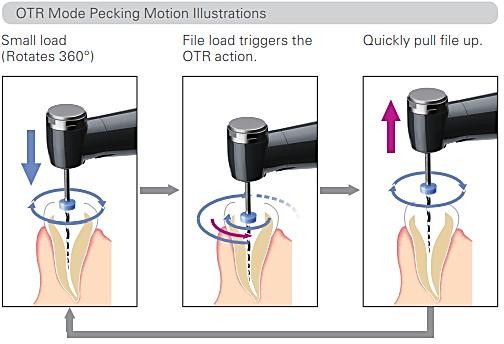


1. Start Filing

Step on the foot switch to start the motor handpiece. In OTR mode appears in the rotation speed window when the motormis running

EFFECTIVE OTR PROCEDURE-

* 1. Pre-flaring- for pre-flaring select M3 button
  2. Glide path- to make a glide path, use OTR function or hand-files manually. Use a pecking motion with OTR function.
  3. Move it delicately up and down in a pecking motion.

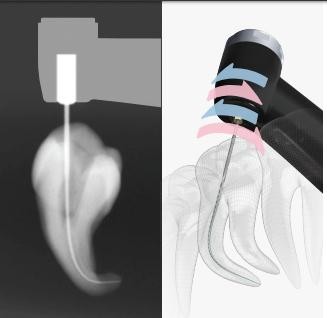


### Tri Auto ZX2

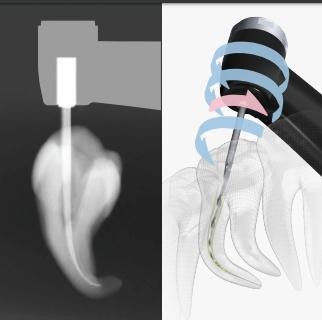
It is a compact, cordless motor with a built-in apex locator. It can be used for obtaining apical patency and creating a glide path using rotary instrumentation. Rotary files even as small as #10 may be used for these procedures.

Features-

* 1. Apical Patency and Glide Path Using a Motor OGP Function (Optimum Glide Path) Using #20 or smaller files, the motor can be used to achieve apical patency and create a glide path. It reproduces the subtle and delicate finger movements of an experienced dentist. Even curved or constricted canals can be treated faster and more safely. Both NiTi files sized #20 or smallerr, or stainless steel files sized #15 or smaller may be used.

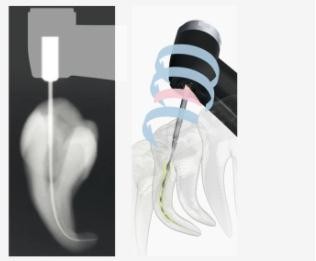


* 1. Safer and Efficient Canal Shaping OTR Function (Optimum Torque Release) - Depending on the load on the file, the motor alternates between forward and reverse rotation with great sensitivity to prevent jamming and file breakage. It is also superior in its ability to follow the shape of even curved canals to reduce ledges and over instrumentation. Tri Auto ZX2 is compatible with standard NiTi files - no need to purchase specialty files.



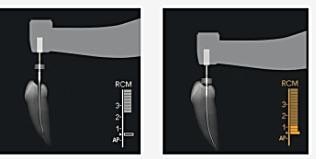
* 1. Prevention of file breakage and micro-cracks-

The file is always subject to mechanical influences in the root canal which could lead to file breakage. For this reason, it is particularly important to limit torque for protecting the file. The OTR function enables the file to reverse its rotational direction upon reaching a certain torque. After rotating in reverse by 90 degrees, the file returns to the cutting direction.



* 1. Automatic stop safety function-

The TriAuto ZX2 motor is linked with the canal measurement function. This feature makes endodontic treatment safer and much more efficient. The file position is shown in the display, and the motor stops or reverses rotation as soon as the file reaches the end of the working length to prevent perforation.



**Integrated measurement function for results with millimeter accuracy-** The apex locator integrated into the handpiece provides exact measurement results irrespective of rinsing fluids in the root canal. On the color display, the practitioner can see the distance of the file from the apex. Monitoring is also

carried out by acoustic signals.

### Easy application - short treatment period

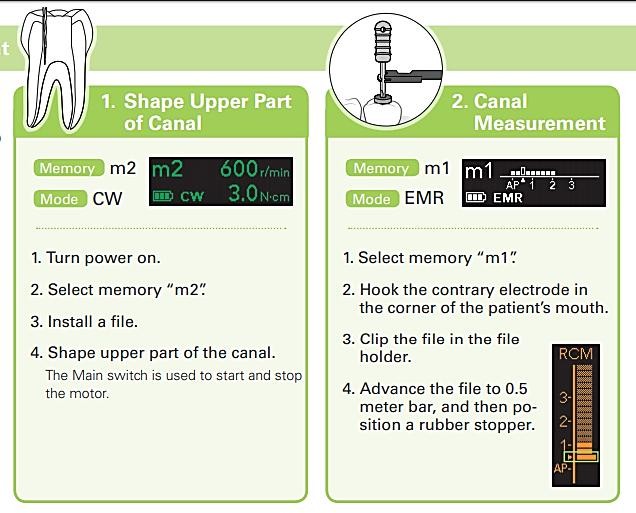
As all preparation stages are carried out mechanically, the practitioner can save a great deal of time. Eight pre-set programs of relevant parameters are stored to ensure short treatment sequences. Depending on requirements, speeds of between 100 and 1,000 rpm are available in the settings.

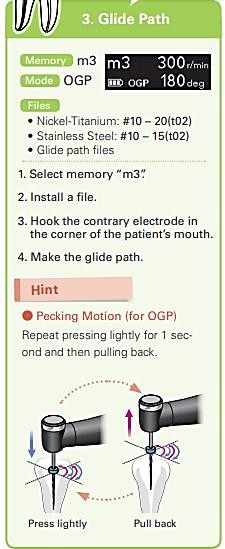
### Small instrument head

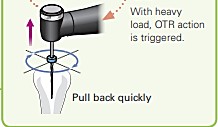
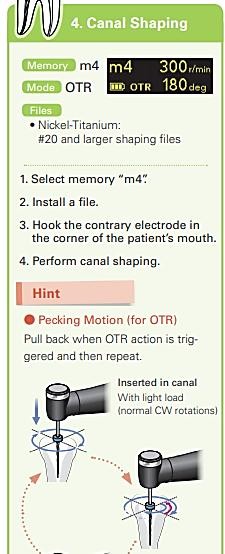
With the small instrument head of the Tri Auto ZX2, the practitioner has a direct view of the preparation area at all times. The internal file electrode acts as a backup here by optimizing vision and enabling a greater working length.

Torque- 4 Ncm or more

Speed- 100±20 - 1000±100 rpm







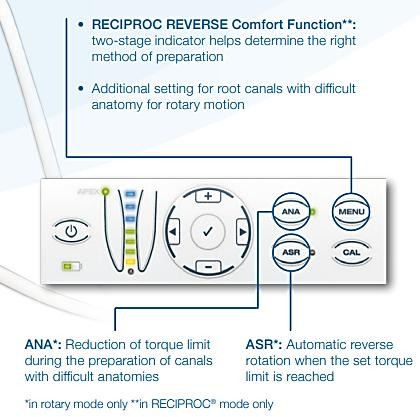
### Vdw Endomotor With Inbuilt Apex Locator – Gold-

Endo motor with integrated apex locator in reciprocating and continuous rotary mode



### Fig-104 Vdw Endomotor With Inbuilt Apex Locator – Gold Features

* Extensive range of reciprocating and continuous rotary file systems
* Perfect interplay in the RECIPROC mode
* Unique RECIPROC REVERSE comfort function
* Torque control with Automatic-Stop-Reverse



High performance for rotary and reciprocating root canal preparation-

* Powerful and safe preparation in torque controlled rotary and reciprocating motion
* Supports an extensive range of rotary and reciprocating file systems
* Store up to 15 individual torque and speed settings
* Battery-operated motor; maintains constant operation even during charging

Powerful preparation and precise length determination in one device- Choose between 3 working mode-

1. Monitor the file progression simultaneously during preparation.
2. Prepare the root canal without length determination.
3. Determinate the working length or monitor the file progression independently of preparation.

### MM Control (Micro-Mega, Besanc¸on Cedex, France)-

Endo motor with torque and speed control + integrated apex locator. It also has the AAR (auto apical reverse) function which reverses the rotation when the file tip reaches the specified apical limit. According to the manufacturer‟s instructions, it is recommended to use the „„0.5‟‟ mark as the apical limit for both the EAL and AAR functions.

### MM Control (Micro-Mega, Besanc¸on Cedex, France)

Features-

* Proven reliability -Controls the speed which remains stable according to the anatomical conditions of the canal.
* Apex locator precision: instant, reliable and precise indication of the apical distance due to the triple-frequency application (100 Hz; 333 Hz und 10 kHz).
* Contra-angle is designed with high-performance composite: unique resistance to shock, cleaning and disinfecting products and sterilization.
* Integrated apex locator- avoids being over-apex.
* Use in continuous rotation- A principle with scientifically proven efficiency versus reciprocation. Apical debris extrusion with reciprocating movement is higher than with continuous rotation.
* Technical features-Speed control: from 100 rpm to 500 rpm. Torque control: from 0.5 to 4 N.cm. Apical distance control: from 0 to 3 mm.

According to Cruz *et al* (2017), the AAR function set at the 0.5 mark of both the MM Control and Root ZX II provided an adequate apical limit of preparation in vitro. However, the EAL function of the MM Control alone was less accurate than Root ZX II, resulting in a higher percentage of readings beyond the AF.

### Disadvantages-

MM Control displays the distances to the apex using light-emitting diodes with different colours. It was noted during the EAL measurements that, when the file was closer to the AF, the light-emitting diodes between 0.5 and APEX were usually flashing in different patterns, requiring more time to obtain a consistent reading.

### CanalPro™ Motors

The CanalPro Jeni and CanalPro CL motors provide the dentist with two smart systems for successful endodontic treatment.

### CanalPro Jeni –

It is a fully automatic, electric controlled endomotor with integrated apex locator which makes preparation amazingly easy, safe and efficient. The Jeni assistance system continuously adapts to the individual root canal anatomy and guides the mechanical and chemical preparation step by step.

### Coltene Canal Pro Cl2 Cordless Endomotor-

It provides a clear view and unobstructed access in all treatment situations. It has clear LCD display and the easy-to-clean keypad.



### Coltene Canal Pro Cl2 Cordless Endomotor

**Features**

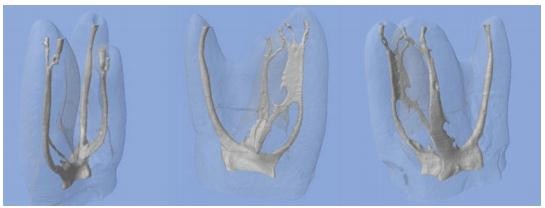
* + Energy-saving, turns off when not used for 10 minutes
  + Memory for up to 5 programs.
  + Auto-reverse modus.
  + 6 head positions allows of contra angle head to be adjusted to your preferred position.
  + Contra angle head is autoclavable at 135°C
  + Rotation Speed (min-1): 140 - 550
  + Torque Level (N·cm): 0.3 - 3.0

## IRRIGATION

One of the most important procedures in root canal treatment is chemo- mechanical preparation of the canal system. Irrigation is complementary to instrumentation in facilitating removal of bacteria, debris and therapeutic materials such as gutta-percha, sealer and medicaments from root canals. The effectiveness of irrigation relies on both the mechanical flushing action and the ability of irrigants to dissolve tissue.

The aims of this procedure are the mechanical detachment of pulp tissue, dentin debris, smear layer (instrumentation products), micro-organisms (planktonic or biofilm) and their products (all together hereafter named substrate) from the root canal wall, their removal out of the root canal system and their chemical dissolution or disruption.77,78

Peters *et al* compared micro–computed tomography scans before and after mechanical instrumentation and found that regardless of the instrumentation technique, 35% or more of the root canal surfaces remained un-instrumented. Lateral canals, fins, and other irregularities might also remain un-instrumented and provide an environment for microbes to colonize and cause disease.79



### Fig.-105 Micro-CT images of a maxillary molar demonstrate the root canal complexity

**OBJECTIVES OF IRRIGATION74**

* + Lavage of debris –

Debridement is accomplished with hand instrumentation. This alone is not able to remove all the tissue remnants in pulp chamber and canals. One must therefore, rely on lavage and some means of chemical debridement of remaining tissue.

* + Tissue dissolution –

Instrumentation alone is not able to remove all pulp tissue from canal, so remaining vital, necrotic or chemically fixed tissue should be removed by irrigation.

* + Antibacterial action –

Bacteria are present in root canal. Instruments may force such bacteria and debris beyond apical foramen, resulting in periapical inflammation and infection.Irrigant, having antibacterial property to eliminate bacteria should be used to sterilize canal.

* + Lubrication –

To facilitate instrumentation in canal and for ease of debris removal canal should be lubricated by irrigants. Files and reamers are much less likely to break when canal walls are lubricated by irrigants.

* + Smear layer removal
  + Lower surface tension – Irrigants should possess low surface tension. Low surface tension promotes flow of fluid into inaccessible areas. High surface tension inhibits the spread of liquid over a surface to limit its ability to penetrate a capillary tube. Alcohol added to an irrigant decreases surface tension.

### IRRIGANTS

**Classification by Bettina Basrani and Gevik Malkhassian78**

1. Antiseptic agents: Sodium hypochlorite (NaOCl), chlorhexidine gluconate (CHX).
2. Decalcifying agents:

Weak : Hydroxyethylidene bisphosphonate or etidrona acid (HEBP). Strong : Ethylene diamine tetra acetic acid (EDTA).

1. Combinations and solutions with detergents-

a. BioPure MTAD and Tetraclean:

BioPure MTAD- an aqueous solution of 3 % doxycycline( 150mg/ml), a broad-spectrum antibiotic; 4.25 % citric acid, a demineralizing agent; and 0.5 % polysorbate 80 detergent

Tetraclean: Composition same as MTAD. Concentration of doxycycline-50mg/ml

1. Anti-microbial agents-

QMiX- contains a CHX analog, triclosan, ( N -cetylN , N , N - trimethylammonium bromide), and EDTA as a decalcifying agent

### Benefits of Using Irrigants in Root Canal Treatment

* Removal of particulate debris and wetting of the canal walls
* Destruction of microorganisms
* Dissolution of organic debris
* Opening of dentinal tubules by removal of the smear layer
* Disinfection and cleaning of areas inaccessible to endodontic instruments

None of the available irrigating solutions can be regarded as optimal. Using a combination of products in the correct irrigation sequence contributes to a successful treatment outcome.

During root canal therapy, endodontic irrigants are delivered to the apical areas to help remove loose debris, dissolve organic tissues, kill microbes, and remove smear layer.78

In conventional needle irrigation, replenishment and exchange of irrigant in the apical third and the effectiveness of chemical debridement are dependent on the depth of penetration. Boutsioukis *et al* (2009) showed in a computational fluid dynamic model that the exchange of irrigant only occurs 1–1.5 mm past a side-vented needle, and the irrigant beyond that point remains stagnant. Chow *et al* (1983) also found that the exchange of irrigant does not extend much beyond the tip of the irrigating needle. Vapor lock that results in trapped air in the apical third of root canals might also hinder the exchange of irrigants and affect the debridement efficacy of irrigants. Studies

have shown that conventional needle irrigation is less effective in cleaning the apical areas compared with the coronal areas of root canal systems.79

So, various techniques of root canal irrigation has been developed.

### Continuous and Intermittent Flushing Techniques

Two flushing methods are currently employed to irrigate root canal systems: the continuous and intermittent.

With the intermittent flush technique, the irrigant is injected in the root canal space with a syringe and the irrigant solution can then be activated; the canal is filled several times after each activation cycle.

Inversely, the continuous flush techniques provide an uninterrupted supply of fresh irrigation solution into the root canal. This technique can provide more effective results and reduce the time required for final irrigation when compared with intermittent irrigation devices. Taking into consideration that chloride (responsible for dissolving the organic tissues and NaOCl’s antibacterial property) is unstable and quickly consumed, a continuous flow of irrigant would make intuitive sense

### IRRIGATION TECHNIQUES

**CLASSIFICATION80**

Throughout the history of endodontics, endeavors have continuously been made to develop more effective irrigant delivery and agitation systems for root canal irrigation.

These systems might be divided into 2 broad categories-

* manual agitation techniques
* machine-assisted agitation devices



### Fig. 106 -Irrigant Agitation techniques and devices

**Machine-assisted Agitation Systems**

### 1. Rotary Brushes-

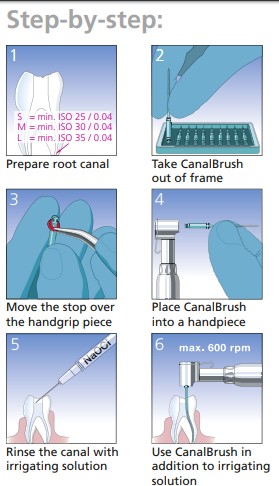
A rotary handpiece–attached microbrush has been used by Ruddle to facilitate debris and smear layer removal from instrumented root canals.74 During the debridement phase, the microbrush rotates at about 300 rpm, causing the bristles to deform into the irregularities of the preparation. This helps to displace residual debris out of the canal in a coronal direction. However, this product has not been commercially available since the patent was approved in 2001.



### Fig. 107 CanalBrush (Coltene Whaledent, Langenau, Germany

A. **CanalBrush (Coltene Whaledent, Langenau, Germany)-**

It is an endodontic microbrush that has recently been made commercially available. This highly flexible microbrush is molded entirely from polypropylene and might be used manually with a rotary action. However, it is more efficacious when attached to a contra-angle handpiece running at 600 rpm. A recent report by Weise *et al* showed that the use of the small and flexible CanalBrush with an irrigant removed debris effectively from simulated canal extensions and irregularities.81



### Fig.108 Highly flexible micro-brush Fig. 108 a steps to use micro brush

**Continuous Irrigation During Rotary Instrumentation**

### Quantec-E irrigation system (SybronEndo, Orange, CA)-

It is a self contained fluid delivery unit that is attached to the Quantec-E Endo System. It uses a pump console, 2 irrigation reservoirs, and tubing to provide continuous irrigation during rotary instrumentation.82



### Fig. 109 Quantec E-irrigation system connected to Quantec Electric motor with tubing to ultra-slow hand-piece

Ideally, continuous irrigant agitation during active rotary instrumentation would generate an increased volume of irrigant, increase irrigant contact. time, and facilitate greater depth of irrigant penetration inside the root canal. This should result in more effective canal debridement compared with syringe needle irrigation. These speculations, however, were not supported by the work of Setlock *et al*, 2003 .

Compared with needle irrigation, Quantec-E irrigation did result in cleaner canal walls and more complete debris and smear layer removal in the coronal third of the canal walls. However, these advantages were not observed in the middle and apical thirds of the root canal.82 This is also confirmed by Walters et al ,2002, who found that there was no significant difference between standard syringe needle irrigation and irrigation with the Quantec-E pump.80

### Self-adjusting file system-83

It has a hollow thin walled cylinder composed of a thin nickel-titanium lattice. It is compressible and adjusts to the anatomy of the root canal. SAF operates with a continuous flow of irrigant (5ml/min) running through the instrument.



### Fig. 110 Self-adjusting file

The vibrating movement of SAF within the irrigant facilitates its cleaning and debriding effects. SAF is designed to efficiently prepare root canals that do not have a round cross section because the compressible file adapts its shape to the canal anatomy.

### The RDT handpiece-head

The RDT handpiece-head has a dual mechanical function. It turns the rotation of the micro-motor into a trans-line in-and-out vibration with an amplitude of

0.4 mm. It also contains a clutch mechanism that allows the SAF to rotate slowly when not engaged in the canal but completely stops the rotation once the file is engaged with the canal walls.



### Fig 110 a RDT hand-piece head

The micromotor is operated at 5000 rpm, which results in 5000 vibrations/min, and the operator uses pecking motions when using the SAF.

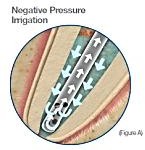
A VATEA irrigation pump-it is used to deliver a constant flow of irrigant. The SAF file is provided with a freely rotating hub connected to a polyethylene tube thus allowing for flow of the irrigant through the hollow file and into the root canal. The irrigant can be delivered into the tube at a rate ranging from 1- 10 mL per minute, with the typical recommended setting of 4 mL per minute.



### Fig 110 b VATEA irrigation pumps

**Pressure alternating devices**

There are 2 apparently dilemmatic phenomena associated with conventional syringe needle delivery of irrigants. It is desirable for the irrigants to be in direct contact with canal walls for effective debris debridement and smear layer removal. It is difficult for these irrigants to reach the apical portions of the canals because of air entrapment, when the needle tips are placed too far away from the apical end of the canals. Conversely, if the needle tips are positioned too close to the apical foramen, there is an increased possibility of irrigant extrusion from the foramen that might result in severe iatrogenic damage to the periapical tissues. Concomitant irrigant delivery and aspiration via the use of pressure alternation devices provide a plausible solution to this problem.80

### Fig.111 Mechanism in Negative Pressure irrigation and Positive Pressure irrigation

**A. Apical Negative Pressure:**

During root canal treatment, pressure is exerted against the root canal wall when the irrigant solution is delivered into the root canal space. Negative pressure refers to a situation in which an enclosed volume has lower pressure than its surrounding.81

### Safety Irrigator (Vista Dental, Racine, WI)-

The Safety-Irrigator is an irrigation/ evacuation system that apically delivers the irrigant under positive pressure through a thin needle containing a lateral opening and evacuates the solution through a large needle at the root canal orifice.

It fits any standard Luerlock syringe. Designed to limit risk of NaOCl accidents, this “negative-pressure” irrigation device comes fully assembled and fitted with a side-vented irrigating needle for added safety.74



### Fig.113 Safety Irrigator

**VPro EndoSafe (VPro; Vista Dental, Racine, WI)-**

It is designed to simultaneously deliver and evacuate irrigant at the working length through its highly flexible, open-ended 30-G needle tip and its folding evacuation hood.



### Fig. 114 VPro EndoSafe

**Features**

1. Fluid flows from apical to coronal region to virtually eliminate clogging.
2. Ratcheting accessory allows for a tactile and audible signal for every 2mL delivered.
3. Adjustable to actual working length.

### The EndoVac System (Discus Dental, Culver City, CA)-

It has three active component parts :

1. the Master Delivery Tip (MDT)
2. the macrocannula
3. the microcannula
4. MDT –

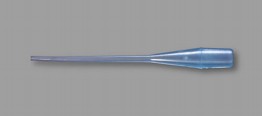
It accommodates a syringe of irrigant, which is expressed through a 20-gauge needle. There is also a plastic suction hood attached around the 20-gauge needle which is connected to clear plastic tubing which inserts into a multiport adaptor which in turn is inserted into the high-volume suction.



### Fig.115 a Master Delivery Tip of endoVac system

1. Macrocannula-

It is meant for single use only. It is attached snugly to an autoclavable aluminium hand piece and is used in an up-and-down pecking motion, while irrigant is simultaneously delivered passively to the pulp chamber . It is used to remove the gross debris and tissue left behind during instrumentation.



### Fig.115 b Macrocannula of EndoVac c handpiece of macrocannula

1. Microcannula-

It contains 12 microscopic holes and is capable of evacuating debris to full working length. It has four sets of three laser-cut, laterally positioned offset holes adjacent to its closed end, 100 μ in diameter and spaced 100 μ apart. These holes act as filters to prevent the clogging of the internal lumen of the microcannula.

The microcannula is attached to an autoclavable aluminium fingerpiece and is used for irrigation of the apical part of the canal when it is positioned at working length. The microcannula has a closed end and should be taken to the full working length to aspirate irrigants and debris. The microcannula can be used in canals that are enlarged with endodontic fi les to ISO size 35 with

0.04 taper or larger.

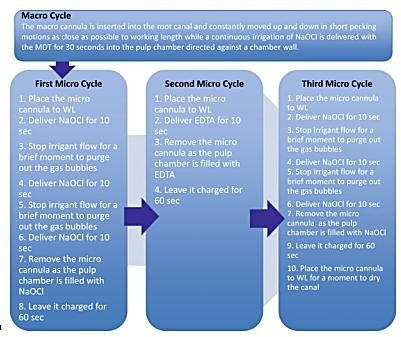
### Mechanism

During irrigation, the MDT delivers irrigant to the pulp chamber and siphons off the excess irrigant to prevent overfl ow. Both the macrocannula and microcannula exert negative pressure that pulls fresh irrigant from the chamber, down the canal to the tip of the cannula, into the cannula and out through the suction hose. Thus, a constant flow of fresh irrigant is delivered by negative pressure to working length, allowing the reaction of hydrolysis to continually occur.81



### 115 d once the microcannula is placed at full working length, the clinician may leave it in place and proceed with irrigant delivery

flow chart illustrating the final irrigation protocol using the EndoVac system-



### Fig.115 e flow chart illustrating the final irrigation protocol using the EndoVac system

1. Debris Removal-

The vacuum action enhances the volume of solution and the circulation of the irrigation solution in the apical end of the root canal.

When the microcannula is blocked by debris, the clinician will experience decreased or complete arrest of irrigant flow. To rectify the situation, the microcannula can be wiped with a gauze or air and water can be blown into it to unclog it. This can also be done with the macrocannula should it also become clogged during its use

1. Smear Layer Removal

Compared to passive ultrasonic irrigation, apical negative-pressure irrigation and manua ldynamic irrigation are more effi cient in removing the smear layer in the apical one third,84

1. Calcium Hydroxide Removal

Although the EndoVac system improves the removal of calcium hydroxide, the apical portion of the canal was not completely free of intracanal medicament. Therefore, the use of the master apical fi le in combination with the EndoVac system may result in better removal of calcium hydroxide.85

1. Sodium Hypochlorite Incidents

Apart from being able to avoid air entrapment, the EndoVac system is also advantageous in its ability to deliver irrigants safely to working length without causing their undue extrusion into the periapex , thereby avoiding NaOCl incidents.81

To avoid NaOCl accidents, clinicians must be careful how far the irrigating needle is placed into the canal. Recommendations include not binding the needle in the canal, not placing the needle close to working length, and using a gentle flow rate to avoid accidents with potentially serious consequences.86

### RinsEndo system (Durr Dental Co)-

It uses pressure-suction technology to deliver the irrigant solution (6.2 mL min¯ ¹ ) and activates (1.6 Hz) it automatically.

Its components are a hand piece, a cannula with a 7 mm exit aperture, and a syringe carrying irrigant. The splash protector aids in the correct positioning of the saliva ejector during removal of contaminated solution. The cannula is ultra thin and highly flexible. It securely locks to the handpiece with a twist. A 7-mm-long exit aperture facilitates the free flow of solution and prevents blocking of the canal.74



### Fig. 116 a The Rinsendo handpiece with disposable cannulas and splash protectors.



**Fig.116 b RinsEndo system (Durr Dental Co.)**

### Mechanism-

The hand piece is powered by a dental air compressor. In the pressure phase,

65 mL of irrigation solution is automatically drawn from the syringe and aspirated into the canal. During the suction phase, the used solution is withdrawn. The pulsed movement of the irrigant, called hydrodynamic activation, adds mechanical cleaning action to the chemical effect of the solution. This combination is very efficient. The pressure-suction cycles change approximately 100 times per minute.

The hydrodynamic activation produced by Rinsendo results in thorough cleaning, right to the apex of the canal. It is not necessary for the cannula to reach the apical area; placement in the coronal third is sufficient for effective debridement.87

It was demonstrated that RinsEndo® removed significantly more debris from the apical root canal irregularities when the needle tip was placed the most coronally.88

Rinsendo automatically limits the delivery air pressure to a maximum of only 5 psi, lower than the pressure generated during manual syringe irrigation. This is an important safety advantage and dramatically minimizes the possibility of pressure-induced apical perforation.

Hauser V, Braun A, Frentzen M (2007) showed Rinse Endo to be superior to conventional static irrigation in dentin penetration of a dye marker; however, a higher risk of apical extrusion of the irrigant was also observed.

RinsEndo® was found to be significantly more effective in removing a bio‐ molecular collagen film than static syringe irrigation *ex vivo* ([**McGill *et al.* 2008**](https://onlinelibrary.wiley.com/doi/full/10.1111/j.1365-2591.2010.01721.x?casa_token=v7QerwZjq6UAAAAA%3A1bnCmGYlj4bjkjcYQAOKGOAbzPha5lDLDPVY9LWNivq0CbejA1L6l8Mz3dahr-BFezRv6YfYb__2pgC1&b35)).

### Sonic irrigation

Tronstad *et al* were the first to report the use of a sonic instrument for endodontics in 1985.

Sonic devices generally oscillate at a frequency of 20–20,000 Hz. Effect of Sonic Irrigation Sonic activation has been shown to be an effective method for disinfecting root canals.

Sabins *et al* and Stamos et al surmised that the more powerful ultrasonic systems removed more dentin debris from the root canal than the less powerful sonic irrigation systems. The positive relationship between acoustic streaming velocity and frequency might explain the superior efficiency of the ultrasonic systems over the sonic systems.

The major systems available to produce sonic/subsonic agitation are the Micromega® Sonic Air®1500 handpiece with an attached Rispi-Sonic® file (Medidenta International Inc.); the EndoActivator® system with attached polymer tips (Dentsply Tulsa Dental Specialties) and the Vibringe® sonic irrigation system (Vibringe B.V.)89

### The EndoActivator System: ( Advanced Endodontics, Santa Barbara, CA, USA)

It is a battery-operated portable handpiece with a 3-speed electric motor. That handpiece accepts one of three different size, disposable, and polymer tips (15/.02, s5/.04, 35/.04). The polymer tips are smooth sided. Operating frequencies were reported by Jiang et al. to be 160, 175, and 190 Hz. These frequencies are different from the manufacturer reported frequencies of 33, 100, and 167 Hz. The tips agitate the irrigating solution placed in the root canal and access opening via needle irrigation.



Fig.117 a **EndoActivator Sysytem b Polymer tips**

It was reported to be able to effectively clean debris from lateral canals, remove the smear layer, and dislodge clumps of simulated biofilm within the curved canals of molar teeth.

In general, 10,000 cycles per minute (cpm) has been shown to optimize debridement and promote disruption of the smear layer and biofilm.89

### Handpiece/Driver

* + Ergonomic, cordless and battery-operated handpiece
  + Contra-angled design for easy access to posterior teeth
  + 3-speed sonic motor providing options of 2,000, 6,000 and 10,000 cpm
  + It is important to not autoclave or submerge the handpiece in cleaning solutions; rather, simply wipe down the handpiece, as desired, with a mild detergent.
  + For infection control, custom protective barrier sleeves have been designed to easily slide over the entire handpiece



### Fig.117 c Custom EndoActivator barrier sleeves are designed to slide over the entire handpiece, including the driver

**Activator Tips**

They are 22 mm in length and are available in three sizes: small (yellow 15/02), medium (red 25/04), and large (blue 35/04). Specific features include:

* + Easy snap-on / snap-off design
  + Strong, flexible, medical-grade polymer composition
  + Clean guard component for the deflection of aerosols
  + Convenient depth gauge rings at 18, 19 and 20 mm
  + The EndoActivator tips are disposable, single-use devices that should not be autoclaved.

### Tip selection-

In fully prepared canals, a tip is selected that fits loosely and to within 2mm of working length. A loose tip will be free to move, enhancing irrigation dynamics (Ahmad, Pitt-Ford and Crum, 1987b). An underprepared canal or selecting a tip that is too large will serve to dampen or restrict tip movement, which in turn will limit its ability to agitate a solution.

Vibrating the tip, in combination with moving the tip up and down in short vertical strokes, synergistically produces a powerful hydrodynamic phenomenon. When the clinical procedure has been completed, support the contra-angled neck of the handpiece and remove the attached activator tip by pulling straight off. Together the activator tip and barrier sleeve should be discarded.90

During use, the action of the EndoActivator tip frequently produces a cloud of debris that can be observed within a fluid-filled pulp chamber. Vibrating the tip, in combination with moving the tip up and down in short vertical strokes, synergistically produces a powerful hydrodynamic phenomenon. In general, 10,000 cycles per minute (cpm) has been shown to optimize debridement and promote disruption of the smear layer and biofilm90. This hydrodynamic activation serves to improve the penetration, circulation and flow of irrigant into the more inaccessible regions of the root canal system (Guerisolo *et al,* 2002)

De Gregorio *et al.* ,2009 (91) found that sonic activation with the EndoActivator® equaled the effectiveness of PUI/UAI in getting irrigant solution into lateral canals 2–4.5 mm from the root apex when EDTA was used. In a later study, de Gregorio et al. 2010reported that the EndoActivator® was superior to needle irrigation in getting irrigating solution to the apex of the root canal preparation and into lateral canals.

### Other use-

It can also be used, in straight or more curved canals, to deliver mineral trioxide aggregate (MTA, Dentsply Tulsa Dental Specialties) into immature teeth exhibiting blunderbuss canals, or into perforating pathological or iatrogenic defects.

In the retreatment situation, clinical trials have shown that the EndoActivator System serves to break up and dislodge remnants of previously placed obturation material.

### Safety-

Desai and Himel 91 2009 first reported on irrigant extrusion and stated that little-to-no extrusion occurred with the use of the EndoActivator.

Boutioukis *et al* 92 2014 found that the use of the EndoActivator® resulted in significantly less extrusion than manual dynamic agitation.

### Disdavantage

Polymer tips used in the EndoActivator system is that they are radiolucent. Although these tips are designed to be disposable and do not break easily during use, it would be difficult to identify them if part of a tip separates inside a canal. Presumably, these tips might be improved by incorporating a radiopacifier in the polymer.90

### Vibringe irrigation system (Vibringe BV, Amsterdam, The Netherlands)

It is a new sonic irrigation system that combines battery-driven vibrations (9000 cpm) with manually operated irrigation of the root canal. It uses the traditional type of syringe/needle delivery but adds sonic vibration.

The Vibringe is a cordless handpiece that fits in a special disposable 10mL LuerLock syringe that is compatible with every irrigation needle.74



Fig.118 **Vibringe irrigation system**

The Vibringe allows delivery and sonic activation of the irrigating solution in one step. It employs a 2-piece syringe with a rechargeable battery. The irrigant is sonically activated, as is the needle that attaches to the syringe.

Research on debris removal has shown that both Vibringe® and EndoActivator® are superior to needle irrigation in both straight and curved canals. Rödig et al.2010 93 reported that use of the Vibringe® resulted in a cleaner apical 1/3 of the canal as compared to needle irrigation alone. However, PUI/UAI was superior over the entire length of the root canal.

### Ultrasonic Irrigation-

Compared with sonic energy, ultrasonic energy produces high frequencies but low amplitudes. The files are designed to oscillate at ultrasonic frequencies of 25–30 kHz.

Two types of ultrasonic irrigation have been described.

1. The first type is combination of simultaneous ultrasonic instrumentation and irrigation (UI).

**2.** The second type, often referred to as passive ultrasonic irrigation (PUI), operates without simultaneous instrumentation.80

### Passive Ultrasonic Irrigation (PUI) –

The term PUI was first used by Weller et al. in 1980 to describe irrigation without simultaneous instrumentation. This non-cutting technology reduces the potential for creating aberrant shapes in the root canal system.

During PUI, energy is transmitted from a file or smooth oscillating wire to the irrigant by means of ultrasonic waves that induce two physical phenomena:

* 1. Acoustic Stream
  2. Cavitation Of The Irrigant Solution

### Acoustic streaming-

It is the rapid movement of fluid in a circular or vortexlike motion around a vibrating file. This leads to formation of small but intense eddy currents or fluid movements around the oscillating instrument. This improves the cleaning ability of the irrigant through hydrodynamic stresses. The shear flow caused by acoustic streaming produces shear stresses along the root canal wall, which can remove debris and bacteria from the wall. The displacement amplitude is at its maximum at the tip of the file, probably causing a directional flow to the coronal part of the root canal.



### Fig.119 a. Acoustic streaming generated around a free moving file (b) within a simulated root canal file

An irregular array of rapid eddying motions was observed concentrated at the apical end of the file. This would be capable of dislodging debris and microorganisms



### Fig.119 c irregular array of rapid eddying motion around the file

1. **Cavitation-**

Cavitation is defined as the creation of steam bubbles or the expansion, contraction and/or distortion of pre-existing bubbles in a liquid. Because of this increase in thermal and mechanical activity of the irrigating solution delivered into the root canal, removal of debris and tissue from the isthmus and removal of the smear layer are more efficient. The bactericidal action of the irrigating solution also increases.89

### Current endodontic ultrasonic machines

1. **Technology-**

The first piezoelectric ultrasonic device for dentistry was developed in 1979 by the Satelec company ; such a device generally consists of the main body that contains the ultrasound generator, a foot pedal, and a handpiece. While the operating frequency is generally fixed and not changeable by the clinician, the main body contains a power dial to control the power setting and thus the power output; increasing the power setting should theoretically increase the amplitude of the oscillation.

A piezoelectric material is contained in the handpiece that oscillates at a frequency of 24–42 kHz in the presence of an electromagnetic field.

In some ultrasonic generators, the tip is pushed to the farthest extent of the amplitude, and with the opposite action being a recoil action. Other more recent ultrasonic generators control both the push and pull motion, resulting in better control 86. The oscillations are transmitted to an ultrasonic tip, some of

which are designed to also deliver water or air, depending on the purpose of use. The flow rate of water delivery can be adjusted on most ultrasonic units.

### Power-

it is recommended to select a low setting initially, and increase the power as needed in the clinical setting for any tip selected for use.

### Commercial ultrasonic devices-

* 1. **ProUltra Piezo by Dentsply Tulsa-**

It is designed to be used with the ProUltra or Satelec handpiece (the Satelec handpiece with LED components). The frequency range generated by the ProUltra Piezo device is 28–36 kHz, which is similar to other ultrasonic devices.



### Fig.120 ProUltra Piezo Ultrasonic device

It features several improvements compared to older generations of ultrasonic devices. These improvements are grouped under the term SmartPower® technology and feature bi-directional power and control in both forward and reverse oscillation directions, allowing the tip to stay centered within a precise operating parameter.

Older ultrasonic devices produce the bi-directional movement by pushing the tip and allowing the tip to recoil on its own. The ProUltra Piezo device maintains the desired power without adjustment of the dial setting when the

tip is loaded during use, and is also able to recognize the intended working frequency of a particular tip, operating the tip at that optimal frequency.

A water flow rate of 0–90 mL/min is possible, and adjustable for use with those ultrasonic tips with a water port.

### Newtron Booster Piezo Ultrasonic Unit (Acteon, France / Clinical Research Dental, London, ON)-

The unit operates in a frequency range of 28 kHz -36 kHz, but every tip is slightly different, and requires its own ideal frequency.



**Fig.121 Newtron Booster Piezo**

The Newtron line also offers a handpiece with an LED light option, which may be helpful if the operator does not have a strong light source or is not using a surgical microscope. The Newtron line also offers variations of their ultrasonic devices, featuring an option for a self-contained irrigation unit, and an option for an “air-active” feature which allows filtered air to be channeled to the tip at low pressure to remove debris

### Current endodontic irrigation attachments-

1. **Ultrasonic irrigation systems- (Continuous ultrasonic irrigation)-**

### ProUltra® PiezoFlow™ Ultrasonic Irrigation Needle,-

The Piezoflow tip is a 25-gauge, blunt-ended stainless steel needle that is tightened into the ultrasonic handpiece with a wrench and used in the mid- range power setting in fully instrumented canals. A syringe or other irrigation

source is attached to the Luer-lock connection on the ultrasonic needle through which irrigant is delivered.



### Fig. 122 ProUltra® PiezoFlow™ Ultrasonic Irrigation Needle

Castelo-Baz *et al.* reported that CUI with the Piezoflow tip was more effective than PUI/UAI in getting irrigant into lateral canals.

Malentacca *et al.* reported that CUI with the Piezoflow tip removed pulp tissue significantly better than needle irrigation and PUI/ UAI. 89

### Debris extrusion-

Utilizing this same system but attaching suction to the ultrasonic tip and placing irrigant in the pulp chamber (similar to the EndoVac system by SybronEndo) proved to be extremely safe . Desai and Himel reported that the use of CUI (using the Burleson et al. set-up) extruded more irrigant out the root apex than needle irrigation.

### VPro™ StreamClean™ system

It offers safe, superlative cleaning power through ultrasonic penetration of irrigants into dentinal tubules and other challenging anatomy.

The autoclavable nickel-titanium tip facilitates incredible access to All regions of the canal, from coronal to apical.

### Features-

* Powerful – it provides superlative and safe cleaning power through the ultrasonic penetration of irrigants into dentinal tubules - and

other challenging areas. It provides safer, enhanced tactile flow through a controlled Safe-T™ syringe.

* Advanced - The VPro's™ autoclavable nickel-titanium tip facilitates incredible access to all regions of the canal, from coronal to apical. Better access means better cleaning.
* Disruptive - It’s truly disruptive - especially to biofilms. This is important because a negative culture is much more likely to result when agitation from ultrasonic energy is used in conjunction with your irrigation regimen.

### Vista Dental Products StreamClean™ Flo-thru tip

It is a 30-gauge blunt-ended NiTi tube with external serrations.



### Fig.123 Vista Dental Products StreamClean™ Flo-thru tip

Yoo *et al.* reported that CUI with the StreamClean™ tip cleaned canals and isthmuses better than needle irrigation in extracted mandibular molars.

Curtis and Sedgley also reported cleaner canals at the 1–3 mm level from the apex using the StreamClean™ tip compared to needle irrigation.

### EndoUltra® device (Vista Dental Products)-

It is the only battery-powered ultrasonic activator.It was introduced with the intention of improving the irrigation stage of endodontic therapy by energizing the irrigant solution with ultrasonic energy.

The cordless device oscillates an activator tip at ~40 kHz to create acoustical streaming and cavitation. Use with ***ENHANCED*** Activator Tips – highly durable titanium, increased flexibility, and **increased** power.



### Fig. 124 EndoUltra Device

**CUI-**

### Time of activation-

The minimal or optimal amount of time needed to ultrasonically activate an irrigant in order for a beneficial effect to occur is unclear.

One study protocol, after complete instrumentation, used passive ultrasonic irrigation for as little as 20 s to measure the penetration of sodium hypochlorite into the dentinal tubules; this amount of time resulted in significantly greater penetration of irrigant in comparison to no agitation or alternative agitation methods.

For the removal of the smear layer, one study reported complete removal of the smear layer after passive ultrasonic irrigation of sodium hypochlorite for 3 min

### Disadvantages

Debate has developed if ultrasonic activation actually is capable of cleaning the apical portions of the root canal due to a phenomenon known as vapor lock. Vapor lock is reported to occur due to the root end being enclosed by the

boney socket which results in gas entrapment at its closed end during irrigation. in vivo status of the root canal system is open unless it becomes blocked with dentin or tissue debris and patency is not maintained.

Boutsioukis *et al*. reported that vapor lock can be removed by increasing the depth of needle penetration, increasing apical preparation size, using an open-ended needle and temporarily increasing fluid flow rate of the irrigant within the root canal.

### Gentlewave (GW) (Sonendo, Laguna Hills, CA, USA) system-

It is based on multi-sonic pressure wave formation. The system uses multisonic energy to develop a broad section of waves within the irrigation solution to clean inside the roots canal system. It has two main components: a handpiece and a console. 74



### Fig.125 Gentle-Wave Irrigation system

**Mechanism-**

Multisonic waves are initiated at the tip of GentleWave™ handpiece, which is positioned inside the pulp chamber. It delivers a stream of treatment solution from the handpiece tip into the pulp chamber while excess fluid is simultaneously removed by the built-in vented suction through the handpiece.

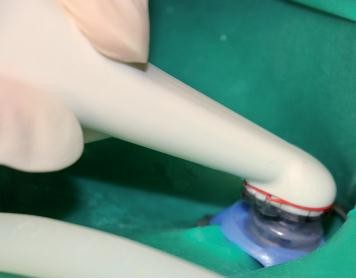
Upon initiation of flow through the treatment tip of the handpiece, the stream of the treatment fluid interacts with the stationary fluid inside the chamber creating a force which causes hydrodynamic cavitation. The continuous

formation of micro-bubbles inside cavitation cloud generates acoustic field with broadband frequency spectrum that travels through the fluid into the entire canal.

### Features-

The system was designed for endodontics in contrast to other devices that were adopted from other medical fields. The GentleWave System provides tissue dissolution of eight and ten times faster than ultrasonic devices and needle irrigation, respectively. It results in negative pressure and zero extrusion at the apex.

To use the GentleWave System, the teeth have to be only minimally instrumented e.g. size 15/04. The resulting fluid dynamics, multisonic sound waves, and sono-chemistry, enable the treatment fluids to penetrate and reach complex areas such as apical-thirds, isthmi, lateral fins, dentinal tubules, and other anastomoses. This cleaning system composes of a portable treatment unit with a single-use sterile handpiece. Irrigant solutions of NaOCl, distilled water and EDTA are included in this cleaning system. Since the treatment instrument should be capitalized does not have to enter the roots, the GentleWave System reduces the need for shaping of the roots using large instrumentation, hence practicing minimal endodontic technique with dentinal conservation.



### Fig. 125 a The hand-piece of the system placed on the subject tooth.

**Efficacy**

Recent clinical study shows that only 3% of the patients experience moderate post-treatment pain, and 97% of successful healing in the teeth treated with the GentleWave System at 12 months.

According to Haapasalo *et al.* the GW System provides tissue dissolution of eight and ten times faster than ultrasonic devices and needle irrigation, respectively.

A study showed that GW system Gentle removed CH within 90 sec using water irrigation alone. According to Molina *et al.,* the GW system showed greater cleaning and reduction in residual debris within the canals than those cleaned conventionally. The efficacy of GW system in removing separated instruments from the root canal has also been reported.

Sigurdsson *et al*. reported 97% successful healing in the teeth treated with the GW System at 12 months.

The efficacy of GW system in removing separated instruments from the root canal has also been reported. 94

### Laser-Activated Irrigation

Activation or agitation of root canal irrigants via the use of lasers is a relatively new concept in endodontics. Previous work with laser has focused on direct canal cleaning and shaping (similar to ultrasonics), disinfection, and smear layer removal. However, issues have arisen in terms of potential damage to the root canal wall dentin, overheating of the root and periodontium, access around the canal curvatures, and the size of the laser tip.

Dental lasers provide greater accessibility of formerly unreachable parts of the tubular network due to their better penetration into dentinal tissues.

### Mechanism-

Blanken and Verdaasdonk first reported the effects of using an Er,Cr:YSGG (erbium chromium- yttrium-scandium-garnet) laser on irrigating fluids. They stated that there was immediate fluid movement after each laser pulse and

they visualized cavitation (expansion and implosion of gas bubbles) effects. This work was confirmed by Blanken *et al.*, De Moor *et al.* and Matsumoto *et al.* , who utilized an Er:YAG laser. 95,96,97

Matsumoto detailed the cavitational effects by stating that the fluid in the canal (water in their study) instantly vaporized (1 μs) next to the laser tip. The vaporized water expanded forming a void (bubble) as the irradiation continued and heated more water on the inner surface of the void. They reported that this expansion occurred for 700 μs. When the laser pulse ceased, the bubble began to shrink, but the pressure of the surrounding fluid caused a violent collapse resulting in acoustic waves which travelled through the fluid-acoustic streaming.



### Fig.126 Laser activated irrigation

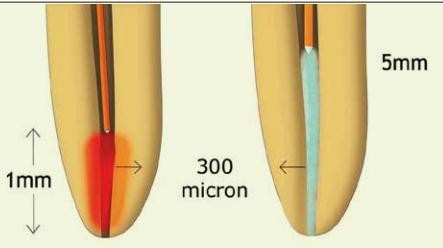
During this process, secondary cavitation bubbles are formed. The fluid flow associated with such an inertial collapse, combined with acoustic streaming resulting from the oscillations of smaller bubbles, could explain the cleaning efficacy of LA.

The secondary cavitation bubbles can also assist in the cleaning of the root canal wall, as they are excited by the bubble collapse of the consecutive laser pulse. As the flow does not penetrate all the way into the apex, a trapped bubble in the apex (most likely a remainder of previous laser pulses) could assist in the cleaning of the apical part of the root canal.98,99

It is these waves (as previously discussed) which result in cleaning of the canal by shearing debris off the walls .

### The laser wavelengths described for cleaning and disinfecting the root canal system are:

erbium: yttrium aluminium garnet (Er:YAG), 2940 nm; erbium, chromium: yttrium scandium galium garnet (Er,Cr:YSGG), 2780 nm; neodimium:yttrium aluminium garnet (Nd:YAG), 1064 nm; diode, 635 to 980 nm; potassium titanyl phosphate (KTP), 532 nm; carbon dioxide (CO2 ), 9600 and 10 600 nm.100



### Fig.127 Position of the laser fibre in traditional laser endodontic technique 1mm short of the apex and in LAI , 5mm short

* + - 1. **Er:Cr:YSGG (WaterLase / Biolase) :**

It uses the hydrokinetic process which gently washes away decay with YSGG laser-energized water droplets. Hydrokinetic energy is produced by combining a spray of atomized water with laser energy. The resulting Waterlase™ (Hydrokinetic™) energy gently and precisely removes a wide range of human tissue including tooth enamel (the hardest substance in the body), and soft tissue (gum tissue) with no heat or discomfort in most cases.



### Fig.128 Waterlase

Intracanal laser therapy-

The final stage of root canal preparation and disinfection is completed with the Waterlase MD laser (Er,Cr:YSGG) using radial-firing tips (Biolase Technology Inc.).

The laser tips are available in two sizes: RFT2 and RFT3 with diameters of 275 µm and 415 µm respectively. The RFT2 tip is inserted 1 mm short of WL, requiring canal preparation sizes of ISO 30 or more while the RFT3 tip is inserted to the junction of middle and apical thirds, requiring canal sizes of ISO 45 or more. These sizes fall well within typical working width preparation sizes.

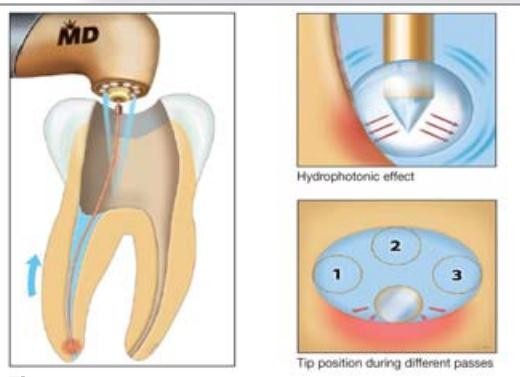


Fig.129 Biolase tip

* + - * 1. Use the RFT2 to perform apical and partial coronal 2/3 cleaning.
        2. Select the recommended laser settings in the wet mode.
        3. Fill canal with sterile solution.
        4. Insert RFT2 tip 1 mm short of working length (WL).
        5. Activate laser on withdrawal of tip coronally at approximately 1 mm/s. Maintain tip in contact with the side surface of the canal wall during the entire apical to coronal pass.
        6. Repeat steps 4 and 5 one or two more times to ensure that the entire inner canal has been cleaned.
        7. Place the RFT3 tip in handpiece to perform final
        8. cleaning of the coronal 2/3.
        9. Fill canal with sterile solution.
        10. Insert the tip to the junction of apical and middle third of the root canal.
        11. Repeat steps 5 and 6.

### Benefits of Waterlase™ Endodontics –

Superior intra-operative and post-operative patient comfort.

Reduced post-operative complications such as inflammation, swelling and pain.

Versatile and effective for root canal preparation.

No vibration and pressure as found with conventional instruments.

Little or no anesthesia. f) More healthy tooth structure is preserved.

### RC Lase :

It is a New endodontic tip that can be used with an Er:YAG laser system. It allows lateral emission of the irradiation (side-firing), through a spiral slit located all along the tip rather than direct emission through a single opening at its far end.

The tip is sealed at its far end preventing the transmission of irradiation to and through the apical foramen of the tooth. This new endodontic side-firing spiral tip RC Lase (Lumenis, Opus Dent, Israel) was designed to fit the shape and the volume of root canal prepared by NiTi rotary instrumentation



### Fig.130 RC Lase Tip

* 2940-nm Er:YAG laser
* 14-mmlong, 200,300,400-micron diameter tapered tip

4 mm of the polyamide sheath were stripped back from the end.

### Side-effects-

Studies have shown side‐effects caused by the use of these types of lasers in the root canal. Carbonization of the root canal and cracks were observed when laser tips were used in the root canal (Matsuoka *et al.* 2005).

Kimura *et al.* (2002) have shown a temperature increase of the root canal wall of 3–6 °C. (98).

### Limitations-

When using lasers inside the root canal, several limitations have to be taken into consideration. Firstly, the laser light is emitted in a straight line from the tip of an optical plain-ended fibre or a laser guide with a divergence angle of only 18 to 20 degrees .With such unidirectional laser beam, it is difficult to gain equal irradiation of the whole root canal dentine surface .

Moreover, the root canal preparation as well as retreatment procedures with laser and plain fibres is dangerous in curved root canals because of the risk of creating ledges and perforations. To improve the surface area of the root canal dentine being irradiated, a helicoidal withdrawing motion from apical to coronal part is proposed when using fibre tips

Besides, new conical side-firing fibre tips with 80% lateral and 20% forward radiation provide complete coverage of intra-canal walls.



### Fig.130 a Handpiece for the Er,Cr:YSGG laser with conical side firing fibre tip for endodontic use (200 μm in diameter).

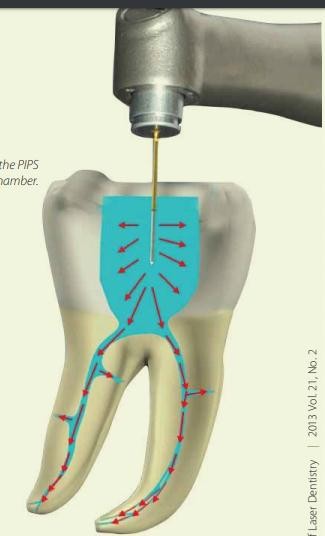
Thermal damage of peri-radicular tissues through the open apical foramen may occur when using the erbium lasers at ablative settings.

### Photon Induced Photoacoustic Streaming (PIPS)

It is the latest application on LAI which uses Er:YAG (2940nm) laser equipped with a conical stripped fibre tip.

PIPS is based on the radial firing stripped tip with laser impulses of sub ablative energies of 20mJ at 15 Hz for an average power of 0.3W at 50μs impulses. Theses impulses induce interaction of water molecules with peak powers of 400W. This creates successive shock waves leading to formation of a powerful streaming of the antibacterial fluid located inside the canal, with no temperature rising.

The laser tip is placed into the coronal access opening of the pulp chamber only and is kept stationary without advancing into the orifice of the canal. This can reduce the need for using larger instruments to create larger canals so that irrigation solutions used during treatment can effectively reach to the apical part of the canal and also canal ramifications.



### Fig.131 a Laser tip placed into coronal access opening

**Advantages-**

It can perform a more comprehensive and effective cleaning of the root canal system. This reduces the risk of reinfections as well as the risk of "ledging" and demineralization.

Due to the minimally invasive nature of PIPS®, more tooth skeleton / root substance is retained.

Since PIPS® only has to be inserted into the coronal third of the canal system and therefore not into the curved root canals, there is no risk of the tips breaking off. The unwanted outflow of the chemical rinsing solution can also be avoided.

Shorter filling and exposure times of the chemical agent enable time savings of up to 20-30 minutes per channel and patient.74,96



### Fig.131 b Radial firing fibre tip with stripped side wall (600 μm in diameter) which is used in the coronal part of root canal for photon initiated photoacoustic streaming (PIPS)

**Efficacy-**

Olivi *et al*. (2014) showed that PIPS can increase the effect of irrigants commonly used in endodontic treatment such as NaOCl.

Jaramillo *et al.* (2011) showed 83% disinfection of the conventional needle irrigation after 20 min of continuous irrigation versus 100% disinfection on PIPS, with a total of 1 min of irrigation with the same solution

Alshahrani *et al.* (2014) also showed that the combination of PIPS+6% NaOCl is more effective than water+PIPS or just irrigation with 6% NaOCl.

### SWEEPS® (Shock Wave Enhanced Emission Photo-acoustic Streaming)

Er:YAG laser modality additionally improves the irrigation and disinfecting efficacy of laser endodontics. By using synchronized pairs of ultra-short pulses, an accelerated collapse of laser-induced bubbles is achieved, leading to enhanced shockwave emission even inside the narrowest root canals.101

According to Jereb *et al,* a study of the potential apical irrigant extrusion during the SWEEPS laser irrigation was carried out, during which irrigation using two standard endodontic irrigation needles (notched open-end and side- vented) was compared with the PIPS and SWEEPS laser irrigation procedures. Both the PIPS and SWEEPS irrigation procedures resulted in a significantly lower apical extrusion compared to the conventional irrigation with endodontic irrigation needles, in agreement with a previous report

**Fotona’s SSP and SWEEPS® Endodontic Treatment** can be best performed with the following multi-wavelength laser systems:

### LightWalker® –

It is a uniquely capable system offering the power of the industry's highest performance Er:YAG and Nd:YAG dental lasers for expanded dual- wavelength treatment options, including the proprietary TwinLight® Endodontic and Periodontal Treatments.



### Fig.132 LightWalker

The top-of-the-line LightWalker AT model features the ultimate in convenience and ergonomic comfort, and is the only dental laser system on the market that includes built-in scanner-ready technology.

### SkyPulse® -

These models are equipped with a 2940 nm Er:YAG laser. Consists of –

1. Er:YAG laser handpiece. It features advanced titanium handpieces that provide robust durability for constant handling and frequent sterilization. SkyPulse’s tipped and tipless Er:YAG handpieces have an integrated air/water spray with adjustable water temperature for additional patient comfort, as well as a quick disconnect system for greater convenience and easier sterilization.
2. Optional diode laser handpiece- Fotona Diode lasers can be used either in contact or non-contact mode. Energy is delivered through a flexible quartz fiber (fiber-optic beam delivery unit) with the corresponding handpieces. The equipment configuration of the system includes two optical fiber assemblies, 200 µm and 300 µm diameter fibers, with corresponding handpieces and a 600µm diameter fiber with the corresponding Genova handpiece.

### TwinLight®-

It is a revolutionary method for cleaning and disinfecting the root canal system using a combination of Er:YAG and Nd:YAG laser energy (available only with the LightWalker laser). Utilizing both Er:YAG and Nd:YAG laser wavelengths in a treatment makes optimum use of the unique laser-tissue interaction characteristics of each wavelength. For example, Er:YAG induces shock

waves in the cleaning solutions and Nd:YAG has a superior bactericidal effect. Combined, they can dramatically improve the outcome of laser- assisted endodontic treatments, guaranteeing maximum efficacy.

### How Does TwinLight Work?

The procedure is preformed in two simple steps:

* 1. Step 1: The revolutionary photon-induced photoacoustic streaming method based on Fotona's Photo Activated Systems Technology or PHASTTM, uses the power of the Er:YAG laser to create non-thermal photoacoustic streaming within the cleaning and debriding solutions introduced in the canal. The canals and subcanals are left clean and the dentinal tubules are free of a smear layer.
  2. Step 2: The deeply penetrating Nd:YAG laser wavelength is utilized to decontaminate dentinal walls up to 1000 μm deep. In this step, the high peakpulse power of the Nd:YAG laser plays an important role as it induces maximum disinfecting temperature pulsing for eliminating bacteria.

### Photon Activated Disinfection (PAD)

Also known as photodynamic therapy (PDT) is based on the concept that a non-toxic, photosensitizing agent known as photosensitizer (PS) can be preferentially localized in certain tissues and subsequently activated by light of the appropriate wavelength to generate singlet oxygen and free radicals that are cytotoxic to cells of the target tissues.

### Components:

1. PAD Solution - A dilute solution containing tolonium chloride which was established as the most effective photosensitizer, packaged either in syringes (for delivery to root canals) or dropper bottles.
2. SaveDent laser - A low power 635nm light source which optimally activates the solution.



### Fig.133 Photon Activated Disinfection Unit (PAD)

**Application:**

1. Canal is washed out thoroughly with sterile saline solution and dries.
2. PAD solution is introduced into canal from syringe via a suitable needle and canal and pulp chamber are filled PAD solution.
3. Solution is agitated in the canal for 60sec using a file, one size smaller than that of which the canal has been prepared.
4. The flexible emitter tip is introduced into the canal until resistance is felt.
5. PAD laser is activated according to manufacturer’s instructions for 150sec at 100mW, when the distance from the entrance in the pulp chamber to the point of resistance in the canal exceeds 10mm.
6. Canal is treated in sections by withdrawing the emitter in 5mm steps and then irradiate each section for 150sec.
7. After canal has been completely treated, canal is washed with sterile saline solution and dried by aspiration followed by sterile paper points.

### How does PAD work?

PAD solution is activated by 635nm light and acts as a photosensitizer, releasing reactive oxygen species which disrupt the membrane of the

microorganism. Independently, the laser and solution have no effect, but in combination produce a powerful antibacterial action.

### Efficacy-

PAD has been shown to kill S.mutans, Actinomyces, Lactobacillus, Veilonella, P.intermedia, F.nucleatum and E.faecalis.

Soukes *et al* showed that combination of methylene blue with red light were able to eliminate 97% E.faecalis biofilm bacteria in root canals.

### Disadvantages:

1. At the concentration provided, PAD solution produces no side effects other than a transient color change in the dentin on the surface of root canal wall. This is removed by the washing process with saline solution after disinfection of the canal.
2. It is the electronic sterilization and devitalization of root canals by means of application of high frequency current that produces a temperature increase inside the root canals. This resluts in vaporization of pulp tissue and bacteria content present therein.
3. The endox system has a control panel with several controls ans 2 sockets, one for the positive needle electrode and other for the neutral electrode. 100

Currently LAD is not considered as an alternative, but rather as a possible supplement to standard protocols of root canal disinfection already in use.

### ANILAD (AUGMENTED ADVANCED NON-INVASIVE LIGHT ACTIVATED DISINFECTION)

The introduction of antimicrobial light activated therapy (LAT) for the elimnation of biofilm-mediated microbial infections is revolutionizing current concepts of disinfection.

### Principle:

LAT involves killing of microorganisms, when a photosnsitizer selectively accumulated in microbial cell is activated by a specific wavelength of light to produce oxygen-based free radicals.

The treatment consists of 2 steps:

1. Administering the photosensitizing composition.
2. Irradiating the admininstered area with suitable corresponding wavelength (IV Light)

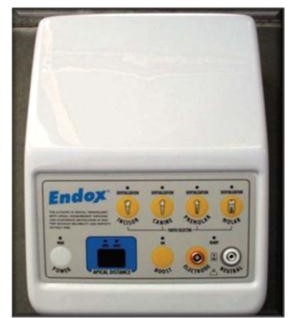
Because this technique could achieve disinfection without significant enlargement of root canal, it was termed as advanced non-invasive light activated disinfection (ANILAD)

### Advantages:

1. 100% removal of biofilm bacteria from root canal dentin.
2. More effective than any other currently available root canal disinfection procedures.
3. Cost effectiveness, non-invasive and easy to administer.
4. Significantly inactivates and eliminates bacterial biofilm better than any of the currently available root canal treatements.
5. Cytotoxicity is signifiacntly lower than NaOCl.

### ENDOX PLUS SYSTEM (Anfratron Technologies GmbH, Wasserburg, Germany) 102

The Endox Plus ystem is a newer version of the Endox system developed to promote disinfection of the root canal system. Similarly to its original version, this device included a fine surgical stainless steel needle that cats as an active electrode, transmitting electrical impulses within the root canal (Cassanelli *et a*l. 2008). Its operating system is based on high frequency alternating current (HFAC).



### Fig.134 ENDOX PLUS SYSTEM (Anfratron Technologies GmbH, Wasserburg, Germany)

The differences between the previous and current version in an attempt to improve its performaces are the:

1. Higher frequency – 312.5 to 315 kHz.
2. Higher potency – 110W/140ms to 180 W/120ms.

### Disadvantage:

Dose not show great antimicrobial actions.

### Ozone based Delivery System

Ozone is a triatomic molecule consisting of three oxygen atoms. It is applied to oral tissues in the forms of ozonated water, ozonated olive oil and oxygen/ozone gas. It is unstable and dissociates readily back into oxygen (O2), thus liberating so-called singlet oxygen (O1), which is a strong oxidizing agent which further impose the deleterious effect on microorganisms.

Various delivery systems available for endodontic irrigation like Neo Ozone Water-S unit, HealOzone (Kavo) unit, the OzoTop unit.



### Fig.135 HealOzone (Kavo) unit

**Mechanism-**

Ozone very efficiently kills cavity-causing bacteria in and on the teeth. The ozone unit produces ozone from oxygen by one of two methods:

The ozone unit can produce ozone from oxygen in the ambient air (Low Dosage mode) or from pure oxygen supplied by an oxygen bottle (High Dosage mode). The latter method generates higher concentrations of ozone gas.

It uses high voltage to convert oxygen into ozone. The ozone generated by the machine is channelled through the handpiece to the affected tooth or root canals in order to treat the carious lesions. After treatment, the ozone gas is then suctioned off, dried and converted back into oxygen by the ozone neutralizer.

### Advantages-

* No anaesthesia, no drilling, no pain
* No complications
* No fillings needed in many cases
* Maximum preservation of healthy tooth structure
* Ozone-treated teeth are more resistant to caries.

Nagayoshi *et al*. found that ozonated water (0.5–4 mg/L) was highly effective in killing both gram positive and negative micro-organisms. Gram negative bacteria, such as Porphyromonas (P.) endodontalis and P. gingivalis were substantially more sensitive to ozonated water than gram positive oral streptococci and C. albicans in pure culture.

Notably, when the specimen was irrigated with sonication, ozonated water had nearly the same antimicrobial activity as 2.5% NaOCl.

### Recommendation-

Ozone works best when there is less organic debris remaining. Therefore, the recommendation is to use either ozonated water or ozone gas at the end of the cleaning and shaping process.

It is effective when it is used in sufficient concentration, for an adequate time. Ozone will not be effective if too little dose of ozone is delivered or it is not delivered appropriately.

## OBTURATION

### Obturation of the Cleaned and Shaped Root Canal System

The final stage of endodontic treatment is to fill the entire root canal system and all its complex anatomic pathways completely and densely with non- irritating hermetic sealing agents. Although thorough bio-mechanical instrumentation of the root canal is necessary to clean the root canal and enhance success, complete obturation is also essential to prevent latent fluid penetration into the root canal space.

Total obliteration of the canal space and perfect scaling of the apical foramen at the dentin-cemcntum junction and accessory canals at locations other than the root apex with an inert, dimensionally stable, and biologically compatible material arc the goals for consistently successful endodontic treatment . 103

### A three-dimensionally well-filled root canal system does the following:104

1. Prevents percolation and microleakage of periapical exudate into the root canal space.

An incompletely filled canal allows percolation of tissue exudate into the unfilled portion of the root canal, where it would stagnate. Subsequent breakdown of tissue fluids diffusing out into the periapical tissues would act as a physiochemical irritant to produce periapical inflammation.

1. Prevents reinfection.

Thorough sealing of the apical foramina prevents microorganisms from reinfecting the root canal during transient bacteremia. Bacteria transported to the periapical area may lodge, reenter, and reinfect the root canal and subsequently affect the periapical tissues.)

1. Creates a favorable biologic environment for the process of tissue healing to take place

### History

Before 1800, root canal filling, when done, was limited to gold. Subsequent obturations with various metals, oxychloride of zinc, paraffin, and amalgam resulted in various degrees of success and satisfaction.

In 1847, Hill developed the first gutta-percha root canal filling material known as “Hill’s stopping.”203 The preparation, which consisted principally of bleached gutta-percha and carbonate of lime and quartz, was patented in 1848 and introduced to the dental profession

In 1867, Bowman made claim (before the St. Louis Dental Society) of the first use of gutta-percha for canal filling in an extracted first molar.

In 1883, Perry claimed that he had been using a pointed gold wire wrapped with some soft gutta-percha (the origin of the present-day core carrier technique)

In 1883, Perry claimed that he had been using a pointed gold wire wrapped with some soft gutta-percha. He also began using gutta-percha rolled into points and packed into the canal. Perry then used shellac warmed over a lamp and rolled the cones into a point of desired size, based on canal shape and length. Before placing the final gutta-percha point, he saturated the tooth cavity with alcohol; capillary attraction let the alcohol run into the canal, softening the shellac so that the gutta-percha could be packed (the forerunner of a chemical-softening technique)

In 1887, the S.S. White Company began to manufacture gutta-percha points.

In 1893, Rollins introduced a new type of gutta-percha to which he added vermilion.

In 1914, The softening and dissolution of the gutta-percha to serve as the cementing agent, through the use of resins was introduced by Callahan.

Over the past 70 to 80 years, the dental community has seen attempts to improve on the nature of root canal obturation with these cements and with variations in the delivery of gutta-percha to the prepared canal system

### APPROPRIATE TIME FOR OBTURATION-

* 1. The tooth is asymptomatic
  2. The canal is dry
  3. There is no sinus-tract
  4. There is no foul order
  5. The temporary filling is intact

### ROOT CANAL-FILLING MATERIALS-

**Materials used can be classified as follows-**

According to Cohen104

ROOT CANAL CEMENT SEALERS-

* + 1. zinc oxide–eugenol formulations
    2. calcium hydroxide sealers
    3. glass ionomer sealers
    4. Resin based sealers
       1. epoxy resin
       2. methacrylate resin) sealers
    5. silicone sealers
    6. recently introduced calcium silicate–based sealers CORE MATERIALS

1. silver cone
2. gutta-percha
3. Active GP
4. Resilon
5. Custom cones

### METHODS OF OBTURATION

The methods are listed as follows:

1. Solid Core Gutta-Percha with Sealants
2. Cold gutta-percha points
   1. Lateral compaction
   2. Variations of lateral compaction
3. Chemically plasticized cold gutta-percha
   1. Essential oil and solvents
      1. Eucalyptol
      2. Chloroform
      3. Halothane
4. Canal-warmed gutta-percha
   1. Vertical compaction
   2. System B compaction
   3. Sectional compaction
   4. Lateral/vertical compaction

a. Endotec II

* 1. Thermomechanical compaction

1. Microscale System, IC Engine Plugger and Maillefer Condenser
2. Hybrid lechnique
3. IS Quick-Fil
4. Ultrasonic plasticizing
5. Thermoplasticized gutta percha
   1. Syringe Insertion .
      1. Obtura
      2. Inject-R-Fill, backfill 2.solid core carrier insertion
         1. Thermafil and Denftil
         2. soft core and three Dee GP
         3. silver points
6. Apical-Third Filling
   1. Lightspeed Simpliﬁll
   2. Dentin chip
   3. Calcium hydroxide
7. Injection or spiral filling
8. Cements
9. Pastes
10. Plastics
11. Calcium phosphate

### According to Grossman:

* + Cold lateral condensation
  + Warm vertical condensation (warm guttapercha)
  + Continuous wave compaction technique
  + McSpadden thermomechanical compaction
  + Thermo-plasticized gutta-percha injection
  + Carrier-based gutta-percha
    - Thermafil thermoplasticized
    - Simplifil sectional obturation
  + Chemically plasticized gutta-percha
  + Custom cone

### Warm Gutta-Percha-

Several techniques have been used to facilitate the placement of gutta- percha, including cold and warm lateral compaction, warm vertical compaction, injectable systems, carrier-based obturation and thermomechanical compaction.

All of these techniques require various degrees of clinical proficiency and, depending on the canal system that is to be obturated, certain techniques may be more appropriate than others.

For example, when a tooth has a large internal resorption defect in the canal,cold lateral compaction may not adequately fill all of the canal space, whereas vertically compacting or injecting warm gutta-percha may provide a more3D obturation. Considering the multitude of canal ramifications in any given tooth, it may be impossible to fill these spaces three-dimensionally unless the gutta-percha is heated.

### Indications

* Maximum condensation is desired
* Tooth with internal resorption or with a large lateral canal.
* It may be used after routine lateral condensation if the post-filling radiograph indicates that the entire prepared canal has not been filled using heated pluggers, the canal filling is removed down to the apical few millimeters and recondensed with a cold plugger to account for any shrinkage. Then warmed gutta-percha segments are repacked down into the prepared canal to gain a more desirable result

### Heating devices for warm gutta-percha compaction technique-

1. **Touch n heat (SybronEndo)-**

Masreleiz’s Touch ’n Heat electric heat carrier (Kerr Endo­dontics) dramatically improved the downpack procedure in both speed and consistency. It was able to deliver its heat carrier at full temperature in less than 2 seconds and, because the electric heat carrier did not cool until switched off, it became easier to avoid pulling the gutta-percha cone out during heating and condensation routines.105

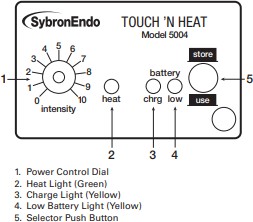
The Schilder heat carrier has been essentially superseded by the Touch ’n Heat 5004 (SybronEndo/Analytic; Irvine, Calif.), an electronic device specially developed for the warm gutta-percha technique. Designed by Dr. Herb Schilder. It exhibits the same thermal profile as the original heat carrier but has the advantage of generating heat automatically at the tip of the instrument.

### Other uses-

The device may also be used for hot pulp testing or bleaching by changing the tips and adjusting the heat level. Also used in removal of gutta-percha for postpreparation or re-treatment.



### Fig.136 Touch n heat (SybronEndo)



**Fig 136 a Intensity of heat can be controlled**.

Not only do you have a precisely heated tip to work with, you can control it's temperature as well.

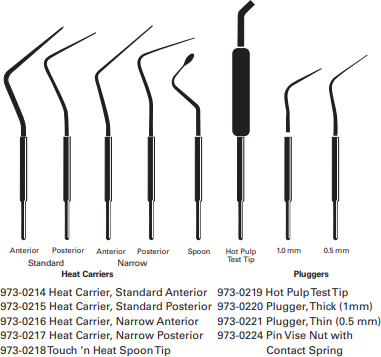
### Tips and Accessories

All tips are heated using a patented method with the heat generated close to the tip’s point. The accessories available for the Touch ’n Heat include a fat spoon, two plugger sizes, narrow and standard anterior or posterior heat carriers plus a hot pulp test tip.

1. **Using the pluggers. The narrow plugger (0.5mm)** is similar to the narrow posterior but has a fat end instead of being pointed. Use this tip in the vertical condensation technique. It is easier to remove gutta-percha

with this tip than with the narrow posterior tip. The thick plugger (1.0mm) is used to prepare post space.

1. **Using the Hot Pulp Test Tip (HPTT**). It is used to test for heat sensitivity. It is important to use some medium to transfer the heat from the pulp test tip to the tooth. A ball of gutta-percha may be softened and molded around the tip edges. Dip the gutta-percha ball in talcum powder or vasoline to prevent it from sticking to the tooth. Consult the temperature/power chart for your desired power setting. Place the tip in firm contact with the tooth, making sure a good contact is established. The black heat shielding tube on the HPTT minimizes your risk of burning the patient.



### Fig.136 b heat carriers and pluggers

The Heat Source is activated, set for “use” and “touch,” and the temperature is set for 200˚C and the power dial at 10.

### Advantage –

the cost, which is about half of the System B.

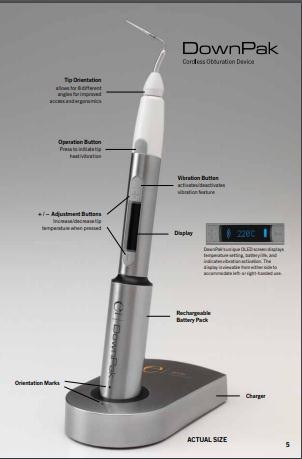
### Disadvantage-

temperature is not controlled, which might lead to over-heating the gutta-percha.

Concern has been expressed that the excessive heat could damage the periodontal ligament in teeth with narrow roots, such as mandibular anteriors. Touch ’n Heat only send heat to the tip and receive no feedback from the tip based on clinical conditions, so it should be used cautiously. The Touch 'n Heat carrier is connected to the unit by a cord, and the tips are interchangeable with those of the System B. Some of the other uses for this device include the ability to sear off excess gutta-percha, use in preparation of post room, and as a pulp testing tool for a response to heat.

### DownPak (Hu-Friedy, Chicago, Illinois) –

The DownPak is a self-contained device that transfers heat and vibration to a spreader or plugger tip. All of the controls are easily accessible on the handle. The combination of precisely controlled heat and vibration at the plugger tip has been demonstrated to fill primary root canals, accessory canals and surface irregularities more completely and more homogeneously than systems using only heat.



### Fig.138 DownPak (Hu-Friedy, Chicago, Illinois)

Clinical studies indicate that vibration may improve the flow of thermo- plasticized gutta percha while also decreasing the number and size of voids (air pockets/empty spaces).(107,108). This more complete seal of the root canal significantly reduces the risk of retreatment.

It can be used in the following root canal obturation procedures:

* + Softening root canal filling material
  + Spreading root canal filling material laterally and vertically
  + Compacting root canal filling material using vibration and heat, separately or in combination
  + Removal of excess gutta percha (or cones) coronally

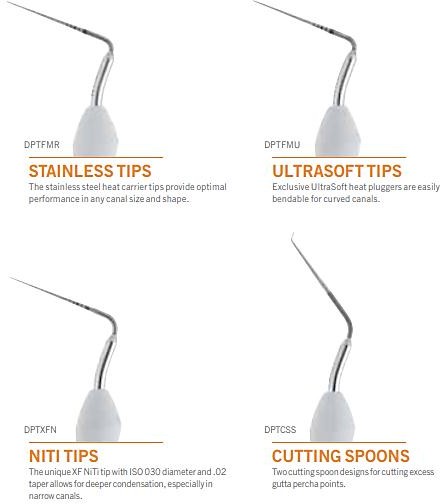
### Feature

It offers the widest selection of tips in various materials, with smaller tip diameters, for perfect adaptation to hard-to-reach areas.

* + Autoclavable for improved asepsis
  + Comprehensive and easily visible identification markings
  + Tip tapers ranging from .02 - .11

### Available in 14 different heat & vibration tip designs:

* + Six new Stainless Steel tip designs improve canal access
  + Three uniquely shapeable UltraSoft tips (ISO 030, 040, 050 in various tapers)
  + Three flexible NiTi tips
  + Two Cutting Spoon tips (large and small)



### Fig.137 a Stainless tips b Ultrasoft tips c NiTi tips d cutting spoons

HEAT- Offers a heat range up to approximately 350º C (662º F).

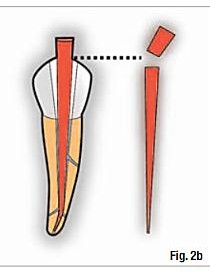
### Technique

The use of the DownPak is similar to a combined vertical and lateral compaction of gutta-percha, so the clinician familiar with these techniques should find the device very user-friendly.

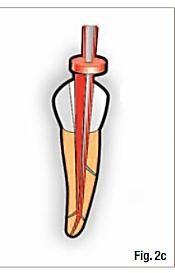
1. Appropriate DownPak tip is selected so that it reaches a depth in the canal that is 3 to 5 mm from the apical terminus. A silicone stop can be adjusted on the tip as a reference point for this measurement



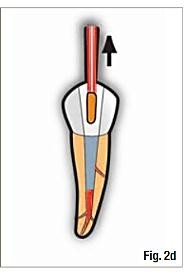
1. Next , the canal walls are coated with sealer and a master gutta-percha (or Resilon) cone is placed in the canal to working length. Using the tip of the heated DownPak, excess coronal gutta-percha is removed to the level of the orifice.



1. With a sustained push, the DownPak tip is introduced into the canal with the heat and vibration modes activated. The tip is then extended down the canal space to the predetermined binding point, 3 to 5 mm from the apical terminus.



1. The tip is rotated rapidly 180 degrees clockwise/counter-clockwise two or three times and heated for two to four seconds; at this time, the tip is removed quickly along with any excess gutta-percha.



Any remaining voids can be sealed coronally with additional accessory cones by applying vertical compaction as described above. (109)

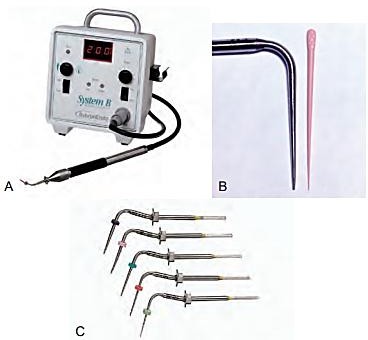
### c. System B- (B for Buchanan; named after Stephan Buchanan) 104, 106

It provides continuous wave of condensation.

* improvement over the Touch’n Heat as it had a temperature setting and could control the amount of heat delivered to the plugger tips.
* has a quick disconnect plug at the end of the handpiece cord so that the handpiece and cord could be autoclaved.
* Using a preset temperature allows the downpack to occur in a more controlled manner with less training
* The System B also accepts Kerr Endodontics' Touch n Heat tips.

This new heat source monitors the temperature at the tip of the heat-carrier pluggers, thus “delivering a precise amount of heat for an indefinite time. Power source (right) provides heat to the tip (on cord). Note the stop on the

tip of the instrument to indicate the correct degree of penetration into the canal to heat the gutta percha.



### Fig138 Continuous Wave Obturation System unit B) System B plugger with non-standard cone of similar taper C) System B Pluggers

The continuous wave compaction technique employs the System B connected to 0.04, 0.06, 0.08, 0.10, or 0.12 tapered stainless steel deadsoft pluggers. The 0.06 tapered plugger also approximates the fine nonstandard gutta- percha cone, the 0.08 plugger the fine-medium cone, the 0.10 plugger the medium cone, and the 0.12 plugger the medium-large cone.

### Recommended temperature-

It is 200°C.

### Steps-

1. After selecting an appropriate master cone, a plugger is prefitted to within 5 to 7 mm of the prepared length. Guss *et al* found the best results were obtained with plugger depth 3 to 4.5 mm from the working length. Recommendations suggest that the best results occur when the plugger is within 5 to 7 mm of the working length, with claims of heat traveling up to 3 mm through gutta-percha. A temperature setting of 250°C or greater may be potentially hazardous.



### Fig.138 a System B plugger fit

1. The System B unit is set to 200°C in the touch mode. The plugger is inserted into the canal orifice and activated to remove excess coronal material. The tip is activated by pressing a ring switch on the handpiece while directing the tip apically. Tthe heat is applied for 10 second. Compaction is initiated by placing a cold plugger against the gutta-percha at the canal orifice. Firm pressure is applied and heat is activated with the device. The plugger is moved rapidly (1 to 2 s) to within 3 mm of the binding point.



### Fig.138 b System B activation and compaction

1. The heat is inactivated while firm pressure is maintained on the plugger for 5 to 10 seconds. After the gutta-percha mass has cooled, a one- second application of heat separates the plugger from the gutta-percha and it is removed.

In ovoid canals, where the canal configuration may prevent the generation of hydraulic forces, an accessory cone can be placed alongside the master cone before compaction.

With type II canals, the master cones are placed in both canals before compaction. A hand plugger is used to stabilize the cone in one canal while the other is being obturated.

1. Filling the space left by the plugger may be accomplished by a thermoplastic injection technique or by fitting an accessory cone into the space with sealer, heating it, and compacting by short applications of heat and vertical pressure.



### Fig.138 c Back-filling by obtura

According to Lipski *et al* (2005), the use of the continuous wave of compaction technique by using the System B Heat Source resulted in an elevation of the root surface temperature by more than 10 degree C.107

A study by Ginali *et al* in 2015, investigated the dynamics of temperature changes on the outer surface of the tooth root during root canal obturation using continuous wave technique and found that maximal temperature increase on the external surface of the root during filling process was found 8mm before apex and equaled +3.8±06°C. 108

A**dvantage** 105

clinician can control the amount of heat going into the heat carrier by the use of the thermostat. The heat is constant once activated and concentrated in the tip of the instrument.

### Disadvantage

involves the cord from the heat carrier to the base that must be managed.

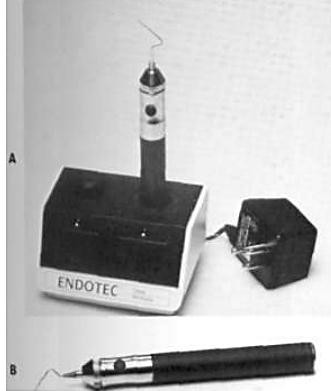
### Warm Lateral Compaction-

Considering the ease and speed of lateral compaction as well as the superior density gained by vertical compaction of warm gutta-percha, Martin developed a device that appears to achieve the best qualities of both techniques. This device was called the Endotec.

### Endotec-

Endotec II (Medidenta Inc; Woodside, N.Y.), the newly designed device is a battery powered, heat-controlled spreader/plugger that ensures complete thermo-softening of any type of gutta-percha. It is supplied with two AA batteries that provide the energy to heat the attached plugger/spreader tips. The quick-change, heated tips are sized equivalent to a No. 30 instrument, are autoclavable, and may be adjusted to any access angulation.

Endotec II tips are available in various taper and tip diameters. The sizes consist of #0.02/20 and #0.02/40. The device is activated and the tip is inserted beside the master cone to within 2 to 4 mm of the apex, using light pressure. Martin claims that the “Endotec combines the best of the two most popular obturation techniques: warm/vertical and the relative simplicity of lateral compaction” (H. Martin, personal communication, December 1999)109



### Fig 139 A. Endotec device in charger B. Endotec gutta-percha heat condenser

**Technique-**

Canal cleaning and shaping for this technique is a continuous taper design with a definite apical stop.

* 1. After the primary point is fitted to full working length, the hand spreader and the Endotec plugger/spreader are fitted as well. At this point, silicone stops are placed to mark the length of canal.
  2. After drying of the canal, a limited amount of sealer is applied.
  3. The primary point is then firmly positioned and gently adapted with a hand or finger spreader. It has also been recommended that one or two additional gutta-percha points be placed to reduce the possibility that the warm plugger will loosen the point when the tip is retracted.
  4. At this juncture the Endotec plugger is placed in the canal to full depth. The activator button is pressed and the heating plugger is moved in a clockwise motion.
  5. The heat button is then released and the plugger cools immediately.
  6. It is now removed from the gutta-percha with a counter-clockwise motion. This lateral compaction has formed a space for an additional point to be added, after which the plugger is again placed, heated, moved clockwise for 10 to 15 seconds, cooled, and retracted counter- clockwise.



### Fig139 a Clockwise and anti-clockwise movement of plugger

* 1. Now the plugger can be used cold to compact the softened gutta- percha, followed again by warming and lateral space preparation for additional points.
  2. In this manner (lateral compaction with the heated plugger to provide space for additional gutta-percha, and the vertical compaction with the cooled plugger to condense the heat-softened gutta-percha) the canal is entirely obturated.
  3. Finally, a cold hand plugger can be used to firmly condense the fused gutta-percha bolus.

### Other uses-

a. can also be used to soften and remove gutta-percha for post preparation or in the event of retreatment.

### Advantage-

Advantage of this technique over lateral condensation is that the heated tip is able to advance apically with minimum exertion because of the softening of the master cone and mass of gutta-percha.

Liewehr *et al* found that the use of warm lateral condensation performed with Endotec resulted in a 14.63% mean increase in weight of the gutta-percha mass which was significantly greater than lateral condensation. 110

Martin H *et al* compared the stress generated with lateral compaction and warm lateral compaction, using the Endotec II, and found that the warm lateral compaction technique created less stress during obturation. 111

A study using a leakage model in vitro by Mc CombD *et al* reported that the Endotec warm lateral condensation has the least leakage, compared with Ultrafil and lateral condensation.

Heat generated by the technique- Evaluation of the effects of warm lateral and warm vertical compaction on periodontal tissues demonstrated that neither technique produced heat-related damage.

### Disadvantage-

Castelli *et al.* found that “some Endotec specimens generated small restrictive inflammatory infiltrates restricted to the root canal opening,” whereas the warm gutta-percha “vertical condensation inflammatory reactions, because of their extensive nature, were probably the source of maintaining discomfort and pain.

### Thermopact (Degussa, France PB 125-223 Neuilly Sur Seine)-109

A new efficient heating device for use in either the lateral or vertical warm gutta-percha condensation technique was described by Sauveur.

The Thermopact consists of a unit containing a transformer and an electronically controlled circuit for heat generation and control, and a handpiece adapted with different-sized spreaders and a heat carrier. The temperature can be selected, regulated, and maintained at any desired level from 40° C to 70° C.



### Fig.140 Thermopact (Degussa, France PB 125-223 Neuilly Sur Seine)

Sauveur observed that chemicals accord great importance on the effect of temperature on the structure of gutta-percha, whereas clinicians, when performing endodontic treatment, seem rather oblivious of the amount of heat to which the guttapercha is subjected.

When gutta-percha burns under high temperature, it looses its organic matrix and homogeneity. The remaining material consists of a white powder of zinc oxide, its principal component.

He therefore suggested that when one is using the Thermopact device, the operating temperature should be set precisely and maintained constant. It should range within the limits of the gutta-percha going from beta (or solid) phase to alpha (or plasticizcd) phase, at approximately 42° C; or from the alpha plasticized phase to the amorphic phase, where partial decomposition begins to occur, approximately at 60° C. The Thermopact should therefore be ideally set and maintained at 42° C for warm lateral condensation, and at about 59° C for warm vertical compaction.

With the Thermopact device set and maintained at 42° C, warm lateral condensation is carried out in a manner similar to the traditional cold lateral condensation method. The difference is that the warm spreaders soften and depress the gutta-percha laterally, allowing the instruments to gently and deeply penetrate to the desired apical level. Therefore more guttapercha cones can be added successively in the space created by the warm spreader and coalesced into a denser mass. The technique produces a homogeneously compacted filling with accurate control of apical extrusion, maximal gutta-percha, and minimal scaler.

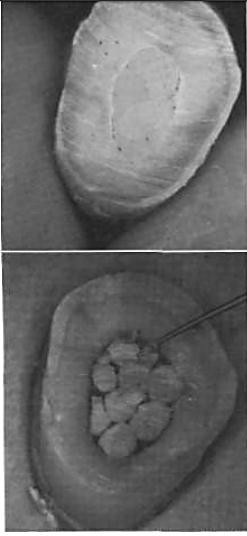


Fig.140 **a Lateral condensation technique. A, Warm lateral condensation with the Thermopact, no sealer used, showing compactness of gutta-percha mass. B, Cold lateral condensation, no sealer used, showing significant spaces between guttapercha cones.**

### Advantages

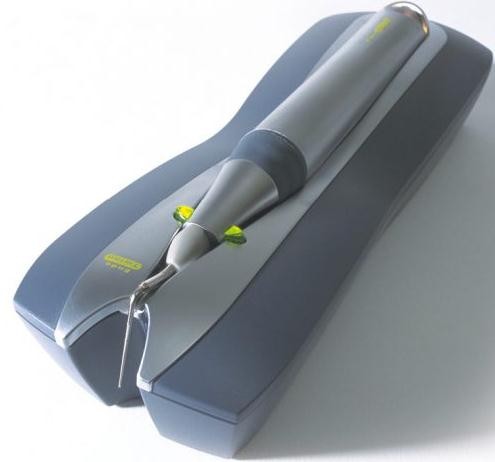
Provide a denser, more compact obturation with a maximum amount of guttapercha and a minimum amount of sealer.

The minimal condensing pressure is a decided advantage in the prevention of root fractures.

### EndoTwinn (Hu-Friedy)

It possesses the ability to vibrate the electronically heated tip.it consists of a charging dock and a rechargeable ergonomic device. It is reported that warm lateral compaction, using both heat and vibration, and warm vertical compaction of gutta-percha provided statistically better replication of defects than cold lateral compaction.

Hu-Friedy introduced the DownPak, a variation of the original EndoTwinn that can be used with either warm lateral or warm vertical compaction techniques.



### Fig 141 EndoTwinn THERMOMECHANICAL COMPACTION OF GUTTA PERCHA-

1. **Ultrasonic Plasticizing-**

### Cavitron ultrasonic scaler (Dentsply/Caulk; Milford, Dela.) –

The technique of plasticizing gutta-percha in the canal with an ultrasonic instrument was first suggested by Moreno from Mexico. He used a Cavitron

ultrasonic scaler (Dentsply/Caulk; Milford, Dela.) with a PR30 insert, but because of its design it could be used only in the anterior mouth.

### Steps involved-

The no. 25 file attached to the PR 30 insert of the ultrasonic unit is placed alongside the primary gutta-percha point and sealer to a depth about 5 mm short of the working length.

The ultrasonic unit with the rheostat set at 1 is activated for 3 to 4 seconds. The ultrasound thermal energy released by vibratory motion of the ultrasonically activated file plasticizes the gutta-percha.

Upon removal of the file, the spreader is inserted immediately to create room for auxiliary cones. The softened primary cone allows a deeper penetration of the spreader, and a greater number of auxiliary cones can therefore be used to obtain better compaction.( 46) .

Final vertical compaction could be done with hand or finger pluggers. Using the Cavitron PR30, they found very little heat rise: 6.35˚C in 6.3 seconds.



### Fig. 142 Cavitron

In a study by Ho et al, the quality of root canal fillings using three gutta-percha obturation techniques was assessed using cold lateral (CL) compaction, ultrasonic lateral (UL) compaction, and warm vertical (WV) compaction. They found that WV compaction and UL compaction produced a significantly denser gutta-percha root filling than CL compaction.

### Advantages of this technique

* low start-up cost, as most dental practices already have ultrasonic equipment.
* It is also easy to learn, as it is based on CL compaction, which is commonly taught.
* It is true that ultrasonic spreading does not speed up the obturation process in comparison with CL compaction, but it improves the quality of the gutta- percha filling.
* Furthermore, the ESI instrument, which is a smooth conical spreader-like instrument, is able to prevent the inadvertent cutting of dentine during the energized compaction process.
* Lateral compaction of gutta-percha with an ultrasonic spreader is an effective alternative to, and requires a lower start-up cost than, WV compaction. Higher quality root canal fillings are likely to result from the implementation of ultrasonic spreading in place of the CL compaction technique.

### Disadvantage 112

When gutta-percha is heated within the root canal, the temperature must be adequate to allow its adaptation without incurring thermal injury to peri- radicular tissues. A 10 degrees Celsius, rise sustained for 1 min is considered compatible with normal bone repair, but higher temperatures or longer application times may cause bone necrosis and its replacement with fatty tissue. Intra-canal temperature rises between 1.66 and 3.74 degrees Celcius apically and between 6.35 and 19.10 degrees Celsius in the mid-root region have been recorded during ultrasonic condensation of gutta-percha.

In a study by Bailey *et al*, maximum temperature rises higher than 10 degrees Celcius were recorded at mid-root level after ultrasonic condensation of the gutta-percha only with the combination of power setting 5 and duration of activation 15 s. It may be inferred that root canal obturation using ultrasonic (Enac) activation of gutta-percha technique is unlikely to cause damage to the periodontal tissue, if the power and time settings are lower than this combination.

### Thermoplastic Injection Techniques-

Taking advantage of the phase changes of gutta-percha and the resultant differences in physical properties, recent developments in gutta-percha delivery systems have dealt with heating or thermo-plasticizing the material to temperatures of 42°C and higher. At these temperatures, gutta-percha changes from solid to being runny and tacky, will stick to the canal walls even without sealer, and will be in the alpha or gamma phase.

The delivery systems employed for thermoplastics take cold gutta-percha, heat it by electricity or a rotating instrument, and then distribute the softened material into the canal, often with an injection tip. Depending upon the technique being used, the gutta-percha may be packed into position with pluggers.

### A. Obtura (Texceed Co., Costa Mesa, Calif.)-

An innovative device, introduced to the profession in 1977, is used in compaction of warm gutta-percha.

It consists of an electrical control unit, a pistol-grip syringe, and specifically designed gutta-percha pellets for use with the Obtura system. The syringe is adapted with silver needles as applicator tip. Relatively flexible silver needles of different sizes (18, 20, 22, and 25 gauge) are used to introduce the plasticizcd gutta-percha into the prepared canal.

By using a silver needle as the applicator tip, the plasticizcd gutta-percha can be injected through a needle as small as 25 gauge. The silver needle keeps the gutta-percha warm as it flows through the tip. which can be bent for easy canal access. Injection time averages less than 20 seconds. Upon completion of the injection, the gutta-percha remains sufficiently plastic for 2 to 3 minutes, which is adequate time for manual condensation. 113

The original **Obtura** was produced by Unitek, but the instrument (called the Gutta-Gun) and the technique did not take hold as well as the company anticipated. Gutta-percha was ejected out of a prototype pressure syringe that

had warmed it to 160˚C. At this temperature, the gutta-percha would flow through an 18-gauge needle.

### Obtura II Heated Gutta-Percha System-

From this early model, a more efficient system was developed and patented. Today, through further improvements, the device is marketed as the **Obtura II Heated Gutta-Percha System** (Obtura-Spartan Corp., Fulton; Mo.) with digitally controlled temperatures ranging from 160˚C to 200˚C while the needle size has been reduced to either 20 gauge (equal to a size 60 file) or 23 gauge (equal to a size 40 file).



### Fig.143 Obtura II Heated Gutta-Percha System

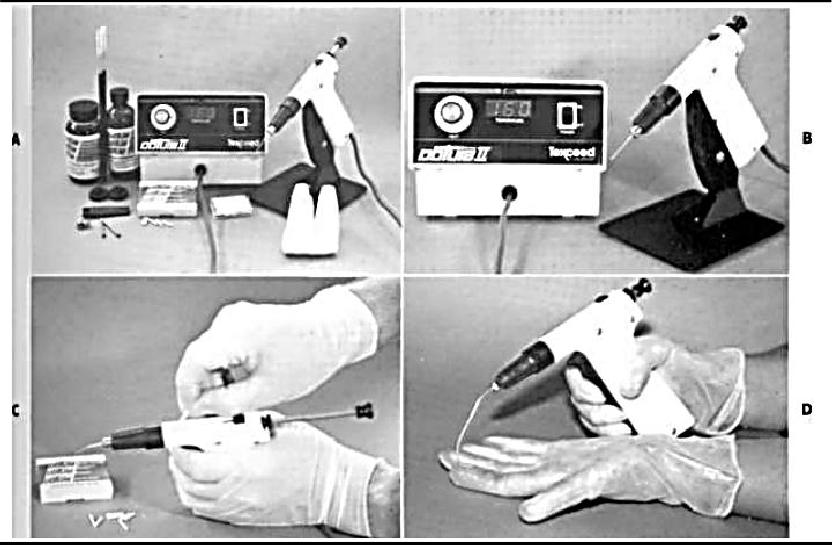


**Fig.143 a needle size has been reduced to either 20 gauge (equal to a size 60 file) or 23 gauge**

The Obtura II system is a second-generation device.

The pistol-grip syringe is made of stronger plastic material that is more resistant to higher temperature. Its highly polished chamber is precisely fitted with a newly designed and well-scaled round plunger. This improves the flow of the softened gutta-percha and is easier to clean after use. The control unit is equipped with a digital readout of temperature and fail-safe circuitry with precise temperature control. Better-designed and -fitted disposable silver needles enhance the injection of thermoplasticized gutta-percha and aid in infection control.

The needles are either 20 or 23 gauge and become quite warm to the touch when heating. The gutta-percha cools to approximately 70°C when being expressed from the needle. The base unit has a knob for controlling the temperature of the gutta-percha in the heating chamber, as the smaller the gauge of the needle the higher the temperature is needed.109



### Fig.143 b The Obtura II, an improved delivery system for the thermoplasticized gutta-percha injection technique. A, The complete Obtura II heated gutta-percha system. B, Electrical control unit with pistol grip syringe handpiece. C, Loading gutta-percha into the barrel of the handpiece. D, At operating temperature, the gutta-percha is extruded from the needle. It is a viscous fluid and sticky at this temperature, has

**good consistency, and is not uncomfortable to the touch. (Courtesy Texceed Corp., Costa Mesa, Calif.)**

### Indications-

It is ideal for use in internal resorption cases and those where the canal is unusual or quite wide.

### Cavity/canal preparation-

According to Gutmann and Rakusin, “continuously tapering funnel from the apical matrix to the canal orifice and a definite constriction at the apex.” The apical constriction limits the flow of the softened guttapercha within the confines of the canal space. This makes it easier to compact densely the filling materials into the irregularities, fins, grooves, and cul-de-sacs of the complex canal system without undue extrusion.

Preparations to size 25 or 30 files at the apical terminus, tapered to a size 60 file at the coronal orifice, have proven perfectly adequate as long as there is sufficient blending of the coronal preparation with the apical preparation.109,113

### Methods of Use-

Method 1

1. Fit a needle to within 4 to 6 mm from the apical termination (use a silicone stop). and ﬁt loosely at that point, sufficient compaction can still occur as long as the needle reaches halfway between the canal oriﬁce and apical terminus in a well-prepared canal.
2. Prefit a cold plugger to the same level (use a Schilder or similar type).
3. Place a thin coat of slow setting sealer on the canal walls. (Sealers such as Roth’s 801, AH Plus, or Sealapex are recommended)
4. Inject the softened gutta-percha. The canal may be totally ﬁlled as the needle is withdrawn, or a small deposit may be made and compacted with the intention of ﬁlling the canal segmentally.
5. Once the deposit is placed, the premeasured plugger is rapidly used to move the gutta-percha apically and laterally. A drop of sealer on the tip of the plugger will prevent its adhering to the gutta-percha. When one is satisfied that the apical third is obturated, a quick radiograph or digital image can be made to ensure the placement. Once viewed, the obturation may be completed.
6. If the filling is short, gutta-percha, if now firm, may be warmed with a hot instrument and then further compacted; the bolus may also be completely removed and the canal refilled. In this event, one may warm the tip of a Hedstroem file, insert it into the gutta-percha, let it cool for 1 minute, and then remove the bolus of gutta-percha. Refilling of the canal can then be done, this time inserting the pluggers to a greater depth, using Easy Flow gutta-percha and/or repreparing the canal first. The radiograph of the final result should show a thoroughly compacted, totally obturated reflection of the tapered canal preparation

### Method2

* 1. Initially place a fitted master point to the apical terminus and follow this with the Obtura needle-tip, depositing a bolus of warm gutta-percha around the point.
  2. This is immediately compacted vertically and laterally. More plasticized gutta-percha is then added and compacted. This technique will better ensure apical closure without overfilling.

### Advantage106

It loads easily, heats gutta-percha to temperature quickly (less than 1 min) and is versatile. it can easily be used to backfill or fill the entire canal. It is ideal for use in internal resorption cases or cases with wide canals.

### Efficacy and Safety of the Thermoplastic Injectable Gutta-Percha Technique-

* Gutmann *et al* found in vitro that the gutta-percha emerged from the needle at 71.2˚C in a body temperature environment. Maximum

temperature elevation on the bone overlying these test teeth was only 1.1˚C over 60 seconds. This appears to be a safe temperature level.114

* Clinical success rates with the injection technique have been reported at 93.1%. 115
* The Obtura II thermoplasticized injectable technique was judged to have the best overall adaptation to the canal walls. This is in agreement with Budd et al. who showed that the high- and low- temperature injectable techniques were significantly better than the lateral condensation technique. It was the only method that obturated the root canal consistently to the working length.

According to Johnson *et al* (1999),

it does not seem that backfilling in 4- to 5mm increments offers any significant advantages over backfilling in 1 increment.

it may be clinically acceptable to backfill canals up to 10 mm in a single increment using sealer and the Obtura II gutta-percha system.

### Disadvantages 106

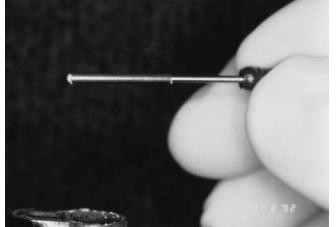
The disadvantage of this system relates to the short working time and once set, the material becomes quite hard and cannot be condensed. Selection of a sealer with any of the guns must consider the working time in presence of heat. Wach’s paste will set up too quickly unless mixed with extra eucalyptol. Variations such as Roth’s or Kerr’s EWT should be used.

### Other thermoplastic injection techniques

1. **Inject-R Fill–Backfilling Technique.**

As stated earlier, the Obtura II is frequently used in “backfilling,” a method for completing total canal obturation after the apical third of the canal has been filled. Another method of backfilling has been developed by Roane at the University of Oklahoma and is marketed as InjectR Fill (Moyco-Union Broach; Bethpage, N.Y.). Inject-R Fill, a miniature-sized metal tube containing conventional gutta-percha and plunger, simplifies warmed vertical compaction by altering the backfilling process. The technique allows for delivery of a

single backfill injection of gutta-percha once the apical segment of a canal has been obturated. 109



### Fig.144 Inject-R-Fill shows protrusion of heat-softened gutta-percha prior to its insertion into the canal.

**c. Ultrafil 3D (Coltène/Whaledent) 109,113**

It differs from the Obtura II in that the temperature of the gutta-percha as extruded is 70° C; thus, it has been termed the low-temperature injection system.



### Fig.145 Ultrafill 3D

Other major differences are that the Ultrafil system consists entirely of three separate components;

1. preloaded gutta-percha-filled canules with 22-gauge stainless steel needles,
2. a heating/ holding unit
3. an autoclavable injection syringe. It is a thermoplastic guttapercha injection technique involving gutta-percha cannulas, a heating unit, and an injection syringe. The system employs three types of gutta-percha cannulas.

* The Regular Set (white cannule) is a low viscosity material that requires 30 minutes to set, not requiring condensation
* The Firm Set (blue cannule) is also a low-viscosity material but differs in that it sets in 4 minutes, condensation is possible, but not required.The manufacturer recommends compaction following the initial set with both materials.
* Endoset (green canule) has a higher viscosity and does not flow as well, must be condensed. It is recommended for techniques employing compaction and sets in 2 minutes.

Steps-

1. The heater is preset at 90°C and does not require adjustment. Each cannula has a 22-gauge stainless steel needle that measures 21 mm in length. The needles can be precurved. Cannulas can be disinfected but are not designed for heat sterilization procedures. Heating time varies, but for a cold unit it takes 10 to 15 minutes. In a warm heater the recommended time is 3 minutes.



### Fig 145 a Cannula needle can be custom bent or precurved

1. After removing the cannula from the heater the needle should be placed on the hot part of the heater for several seconds. The gutta- percha remains able to flow for 45 to 60 seconds depending on the viscosity.



1. The Ultrafil technique docs not advocate manual compaction. If desired, pluggers should be dipped in isopropyl alcohol before use to prevent adhesion and dislodgment of the lacky gutta-percha. Hand condensation with pluggers is done with a light tapping pressure rather than a forceful vertical compaction.

### Calamus flow obturation delivery system (DENTSPLY Tulsa Dental Specialties)

It is a thermoplastic device equipped with a cartridge system with 20- and 23- gauge needles. The unit permits control of temperature and also the flow rate. Pluggers are also available for use with the system. The 360 degree activation switch allows great tactile sensation during use.



### Fig.146 Calamus flow obturation delivery system

1. **Elements Obturation Unit (SybronEndo)**

The Elements Obturation Unit combines our System B™ technology with a motor-driven extruder handpiece to make obturation efficient, predictable, and accurate. From down-pack to backfill, it puts the Continuous Wave of Condensation Technique into one simple-to-operate device that takes up only 1/3 the space of two separate machines.



### Fig.147 Elements Obturation Unit (SybronEndo)

**System B**

* One-touch controls for down-pack, backfill and hot pulp testing
* Each function has preset temperature and duration
* Tip temperature is continuously maintained and displayed
* Time-out feature prevents overheating
* Automatic shut-off precludes using wrong or worn-out tip
* Plugger heats instantly for immediate use

### Extruder

* Motorized handpiece eliminates hand fatigue and precludes voids
* Pencil-grip handpiece enhances control and fits standard handpiece holders
* Precise temperature control for consistency
* Extra-long pre-bent needles offer convenience and unprecedented visibility
* Heats quickly and shuts off automatically
* Handpiece shows remaining material

### Handpieces

* Plugger and extruder handpieces are light-weight, strong and durable
* Insulation technology keeps handpieces cool for you and the patient
* Aluminium shields minimize downtime use one while autoclaving the other

Matched Autofit pluggers replicate the canal shape and maximize condensation forces to move fill material and sealer into all areas of the root canal, including lateral canals, which ensures a complete fill.



### 0.04 taper plugger

The cartridges come with 20-, 23-, and 25-gauge needles for gutta-percha and 20- and 23-gauges for RealSeal.

“If you do warm lateral, vertical, or continuous wave condensation or full - length syringe filling of canals, the Elements Obturation Unit is the most sophisticated filling device available in the world of endodontics today."

-L. Stephen Buchanan, DDS, FICD, FACD

### HotShot

The HotShot delivery system (Discus Dental [now part of Philips Oral Healthcare) is a cordless thermoplastic device that has a heating range from 150°C to 230°C .

The unit is cordless and can be used with either gutta-percha or Resilon. Needles are available in 20, 23, and 25 gauges.



### Fig.148 HotShot delivery system (Discus Dental [now part of Philips Oral Healthcare)

1. **Diadent Gun -**

It is a cordless obturation system that extrudes warm gutta percha to backfill root canals.



### Fig.149 Diadent Gun

**Features-**

* Superior Silver Alloy Gun Tip: reduces chances of accidental breakage
* 360° Swivel Heat Chamber: allows safe adjustments to gun tip’s direction. Versatile and convenient, backfilling maxillary teeth is easy
* Heat Chamber with a Lid: Keeps the heat chamber clean from dirt and dust
* Ergonomic Design: Reduces hand fatigue, offers comfort and tactile feedback.

### Technical Data:

Setting Temperature:160, 180, 200°C Charging time: Approx. 2 hrs 30 min

Operation time per full charge: 20 times per four and half (4.5) min<

### Advantages:

* Cordless, lightweight, and compact design allows complete freedom of movement
* Fast and continuous flow of filling material tightly seals the canal
* Variable Temperature Settings (160°C, 180°C, 200°C): precise control of obturation flow
* Quick Heating System: temperature reaches 200°C within 25 seconds
* Ergonomically designed 360° swivel tip offers improved access
* Thinner tip can easily fill narrow root canals

### WOODPECKER FI-P & FI-G (GUTTA PERCHA OBTURATION SYSTEM)-

1. **Fi-G**

It adopts wireless, vertical type and single button design which brings easy operation.



### Fig.150 Fi-G obturation system

**Features-**

* + Quick heating within 15 seconds
  + 0.5mm injection needle (set of 6 models of tip)-easy to reach the apical 3mm of canal resulting in better filling
  + 360-degree rotatable injection needle- it can also be bent to facilitate multi-angle filling.
  + Dual screen display- enables convenient operations in different angles and teeth-positions
  + Safe protection system- 10 minutes after operation, the device will automatically power off

### Technical Specification-

4 Available temperature- 150°C-180°C-200°C-230°C

Duration after full charging- if each operation lasts for 10 mins, it can work for 15 times

### Fi-P

It adopts wireless, horizontal type, temperature adjusting design for obturation.



### Fig. 151 Fi-P obturation system

**Features-**

* + 0.2 second heating time- the 10 second automatic power cut-off protection ensures safer operation
  + 0.35mm pre-bend tip (set of 9 models tip)- thinner tips can penetrate deep into narrow root canal, providing better filling
  + Conversion system ensures smooth cutting of gutta-percha
  + Display battery level, temperature and status on screen
  + Both visual and auditory prompt for safe operation

### Technical Specification-

4 Available temperature- 150°C-180°C-200°C-230°C

Duration after full charging- if each operation lasts for 10 mins, it can work for 1500 times

### BeeFill Gutta Percha Obturator (VDW)-

Obturation device for Downpack and Backfill technique.



### Fig.152 BeeFill Gutta Percha Obturator (VDW)

**Features-**

* + Preset buttons to save preferred settings
  + Ergonomic handpiece with 360° operation
  + Clear Visibility of the root canal entrance because of slim handpieces and extra-long cannulas
  + Safe use due to visual and audible signals

### Downpack: Heat pluggers

* + Heating, condensing and searing off gutta-percha
  + Continuous Wave or Schilder technique
  + ISO colour coding
  + Click-on system for easy and quick change
  + Several sizes and tapers:

40/.03 | 50/.05 | 60/.06



### Fig.152 a Downpack heat pluggers Backfill: Gutta-percha cartridges

* Injection of warm gutta-percha
* Flexible and long cannula, also suitable for curved root canals
* One cartridge fills 4-6 root canals
* Matching cartridge for each canal anatomy: 25G/0.45mm | 23G/0.60mm | 20G/0.80mm
* 25G cartridge for narrow canals.



### Fig.152 b Gutta-percha cartridges Machtou hand plugger

* + Flexible NiTi hand plugger (size 0) for narrow and curved canals
  + 5 sizes:

Size 0 (ISO 40) NiTi

Size 1-2 (ISO 50 + 60)

Size 3-4 (ISO 80 + 100)

### Pulp sensitivity test:

Thermal response tip



### Fig.137 c Beefill Thermal Response tip Disadvantages of thermoplasticized obturation unit-

1. The difficulties with this system include lack of length control. Both overextension and under-extension are common findings.

Mann and McWalter (124) reported that gutta-percha was underextended or overextended 50% of the time using thermoplastic techniques. El Deeb (125) reported that overextension occurred 75% of the time with vertical condensation of thermoplasticized injectable gutta-percha.

Short fills with the Ultrafil system can occur if the gutta-percha is not heated sufficiently, if leakage of the gutta-percha occurs around the plunger of the

delivery system, or if the gutta-percha is permitted to cool in the needle or cannule before injection.

1. A patent apex may allow extrusion of the thermoplastic filling material into the periapical tissues. The size of the apical preparation of the root canal can be a limiting factor with a thermoplasticized injectable guttapercha technique.
2. Problem encountered *in vitro* with both the Ultrafil and the Obtura system was brittleness of the set material. This brittleness made it difficult to remove the resultant gutta-percha mass from the root canal. (126)

To overcome this drawback, a hybrid technique may be used, in which the clinician begins filling the canal using the lateral compaction technique. When the master cone and several accessory cones have been placed so that the mass is firmly lodged in the apical portion of the canal, a hot plugger is introduced, searing the points off approximately 4 to 5 mm from the apex. Light vertical compaction is applied to restore the integrity of the apical plug of gutta-percha. The remainder of the canal is then filled with thermo-plasticized gutta-percha injected as described.

## PERIRADICULAR SURGERY

Although nonsurgical endodontic treatment is a highly predictable option in most cases, surgery may be indicated for teeth with persistent peri radicular pathosis that have not responded to nonsurgical approaches.

Periradicular surgery, when indicated, should be considered an extension of nonsurgical treatment, because the underlying aetiology of the disease process and the objectives of treatment are the same: prevention or elimination of apical periodontitis. Surgical root canal treatment should not be considered as somehow separate from nonsurgical treatment, although the instruments and techniques are obviously quite different.

### Surgical Access-

The goals of periradicular surgery are to access the affected area, remove the diseased tissue, evaluate the root circumference and root canal system, and

place a biocompatible seal in the form of a root-end filling that can stimulate regeneration of the periodontium. The formation of new cementum on the surgically exposed root surface and on the root-end filling material is essential to regeneration of the periodontium

### Hard-Tissue Access-

Two biologic principles govern the removal of bone for hard tissue access to diseased root ends:

1. healthy hard tissue must be preserved
2. heat generation during the process must be minimized

Temperature increases above normal body temperature in osseous tissues are detrimental. Heating osseous tissue to 117° to 122°F (47° to 50°C) for 1 minute significantly reduces bone formation and is associated with irreversible cellular damage and fatty cell infiltration.

Factors that determine the amount of heat generated during bone removal-

* 1. shape and composition of the bur
  2. the rotational speed
  3. the use of coolant
  4. pressure applied during cutting

### Round bur-

The round bur has the best shape for removing osseous tissue, and it should be used with a gentle brushstroke action.

### Advantages-

1. It readily allows access of coolant to the actual cutting surfaces.
2. Less heat generated with the round burs.
3. Cutting with round burs produced a wound site with less inflammation, which is more favorable for rapid wound healing.
4. Although fissure-type burs cut efficiently on the sides, the tip of the bur is very inefficient because it allows no coolant access.

### Disadvantages-

Use of a diamond bur to remove osseous tissue is inefficient and retards ultimate wound healing. Because of its larger surface area, more of a diamond bur is in contact with the bone tissue. As a result, less coolant reaches the cutting surface, and the bur has a greater tendency to become clogged with residual bone fragments.

The net effect is greater heat generation, increased inflammation, and reduced healing. Use of a coolant during bone cutting is essential. If an appropriate irrigant is not used, temperatures can exceed those known to impair bone healing; histologically, healing can be delayed up to 3 weeks.It also is critical that the coolant reach the cutting surface.

Temperatures can rise above 212°F (100°C) when excess pressure is applied during cutting; this burrows the bur into the bone, where little or no irrigant can reach the cutting tip, hence the recommendation for a gentle brushstroke technique.

Favourable results are obtained provided the surgeon follows the basic tenet of minimizing heat generation by:

1. Using a round fluted bur with coolant and a brushstroke technique.
2. A high-speed handpiece that exhausts air from the base rather than the cutting end is recommended to reduce the risk of air embolism

### a. Impact Air 45 High Speed Surgical Handpiece-

It has a unique 45° angled head that allows maximum access and visibility. It is available with fiber optics. A water or saline line inside the handpiece handle directs a pure water jet (not a mist) directly onto the cutting area. Air is exhausted through the back of the handpiece.



### Fig.153 Impact Air 45 High Speed Surgical Handpiece

**Uses-**

It is also designed for use in periodontal and endodontic procedures, including Apicoectomy (root canal drainage), Osteoplasty (bony contouring), Odontoplasty, Root Resection.

### Features-

1. Fully autoclavable
2. Stainless Steel
3. Office-replaceable turbine
4. Uses standard friction grip burs (push-button bur release)

## FUTURE DEVELOPMENTS

1. **Guided Access Cavity with the Help of Technology-**

An access cavity has to be prepared to gain access to the root canals. This is the ﬁrst invasive step of every root canal treatment and is thus crucial for the outcome, stability and longevity of the tooth. To facilitate disinfection and complete debridement, straight line access to the oriﬁces of the root canals is recommended, but there are also minimal invasive concepts to decrease fracture risk of root ﬁlled teeth. Recently, the concepts of conservative and ultraconservative “ninja” endodontic cavity preparations have emerged. However, there are some cases in which these new approaches for freehand access cavity preparation are difficult to achieve, as in teeth with pulp canal calcification or anatomical abnormalities. Endodontic access to calcified root canals is a challenging task. It is prone to technical failures including alterations of the root canal geometry and substantial loss of dental hard tissue, which may weaken a tooth considerably or result in root perforation. 116

“Guided endodontics,” a novel guided approach for the preparation of apically extended access cavities, was introduced to overcome complications. Miniaturization of conventional instruments has made this technique implementable even for teeth with narrow roots such as mandibular incisors.117

This technique proved to be accurate, expeditious, and operator independent in *in vitro* settings. Although clinical treatment trials are missing, recent clinical case reports show the successful application of this technique in endodontic practice.

Dynamic guidance systems for implant surgery include Robodent, Navident, X-Guide, and image-guided implantology. In endodontics, computer-aided guided navigation systems have demonstrated their potential for clinical practice *in vitro.*

* + **Navident Unit Used for Dynamic Navigation (ClaroNav, Toronto, Canada)-**

Steps involved-

* 1. A small volume CBCT for the patient with slice thickness to be no more than 0.4mm and the export format to include DICOM files in a standard multi file configuration.
  2. Import the DICOM files from the CBCT to the Navident software and proceeded to develop our digital planning for the best path to take in order to locate the calcified canal



**Fig. 154 Navident planning screen. Originally designed for planning dental implant position. In this case used for planning the endodontic access cavity (appears in yellow) through the calcified pulp chamber directly into the radiographically visible coronal entrance to the canal. The operator adjusts the yellow “implant” image, which will be used for the guidance (diameter, length, position and direction) until they are satisfied that this is the best path to take.**

**Axial, coronal and sagittal views are aligned to set up the correct path for the bur to follow.**

* 1. Software will indicate how deep to drill



a. On this picture of the CBCT we have determined that we will have to drill approximately 14mm for us to locate the canal. B. On this Periapical Digital Radiograph we confirm that the canal becomes visible at around 14mm into the tooth, same as on the CBCT.

* 1. Call the patient
  2. Give Local anesthetic to enable the Navident system to track the patient’s maxilla, an optical tracking tag (“Head-Tracker”) should be secured on the patient’s head. The black and white pattern on the tag is recognized and being constantly tracked by the system’s optical tracking sensor, providing the system with the accurate position of the patient’s jaw at any time during the procedure. The patient’s Jaw is represented on the Navident’s screen by its CBCT image, functioning as a map, with the operator’s instrument, such as a drill, superimposed on it.
  3. Prior to starting the navigated access, the patient’s CBCT scan has to be mapped to the actual jaw. This process is called Registration. Navident provides an alternative registration method, called Trace Registration. This method does not require the use of an artificial fiducial marker. Instead it utilizes the already existing, radiographically distinct anatomical structures in the jaw, such as teeth, abutments and even bone.
  4. In the Navident software, three maxillary teeth will be marked on the CBCT scan. These teeth surfaces is then traced with a tracer tool that is also tracked by the Navident’s optical positioning sensor. During the tracing, the system continuously samples and records points on the traced teeth, which are then matched with the CBCT data, to register it with the physical patient’s jaw. The whole process takes no more than one minute.
  5. Following this step, the high-speed handpiece, also tracked by the system, is calibrated in a short two-step process: the axis is calibrated first, followed by calibration of the drill’s tip. This lets the system

continuously track the bur’s direction and position, and to report it to the user on the Navident screen

* 1. At this point an accuracy check was done by placing the tip of the bur on the tooth to be accessed to make sure that it corresponded to the exact point on the tooth to be treated on the computer screen.
  2. Once this was confirmed, the rubber dam is placed and access into the tooth is started with a small diamond bur. After initial access through the tooth, we can then proceed to use a white 31 mm Munce Discovery bur (CJM Engineering Tech, CA, USA), which its tip had been calibrated and tracked, was then used to attempt to locate the calcified canal. Changes in dentinal coloration could be seen via the microscope and these served as landmarks for us to be able to locate the canal.
  3. Drilling with considerable care and following the landmarks the canal is finally located and negotiated with #08K endodontic file.



**Fig 155 Navident navigation screen. Drill’s image (green) following the pre-planned path for locating the canal on the CBCT image in the different views All the views on the screen show proper alignment.**

**Advantages of Dynamic Navigation**

Navident can calibrate and track both high-speed and low-speed driven burs, piezotome saws and other rigid instruments such as osteotomes or even a dental or an endodontic probe, enabling the clinician with the use of any such device for access opening and surgical procedures.

The Trace Registration method (commercially known as “TaP” = “Trace and Place”) allows the dentist to register the CBCT scan to the patient by selecting three to six radiographically distinct, accessible landmarks on the screen, then tracing them in the patient’s mouth. This method eliminates the need for a special second scan to be taken with a metallic fiducial-marker affixed to the jaw with a thermoplastic stent. Aside of reducing the exposure to radiation, it reduces the chance for errors caused by stent dislocation during the scan and allows for the use of a small volume CBCT. As a consequence, it also minimizes time and cost to the procedure.

Once the handpiece and the bur are calibrated, Navident dynamically presents on the screen the actual place and position where to initiate the access. It also shows where the tip of the bur is in real time, guiding the operator to the predetermined place to locate the canal making the location of calcified and multiple canals a faster and more accurate procedure.

With the aid of this technology, smaller and more accurate accesses can be made. Preservation of valuable dentin is one of the main objectives when preforming any dental procedure. In addition, this technology will allow for the location of canals that otherwise could not be detected and negotiated with more traditional techniques. Dynamic Navigation has also the potential for assisting the surgeon in cases where apical surgery is indicated.

Optically driven, computer-aided, 3D dynamic navigation technology with high-speed drills can achieve minimally invasive access cavities in locating highly difficult simulated calcified canals with mean 2D horizontal deviation of

0.9 mm and a mean 3D deviation of 1.3 mm from the canal orifice, and a mean 3D angular-deviations of 1.7.116

A certain level of technical skill, hand eye coordination, and manual dexterity must be maintained from the drilling entry point to reaching the target while looking at the computer screen. Clinical success can be dependent on the hand skills of the operator because of inaccuracies of hand tremor and perception of 0.25 mm and 0.5 involved with bur and handpiece tracking.118

**Nanodrug Delivery Via Irrigation-**

Nanotechnology is the study, design, creation, synthesis, manipulation, and application of materials, devices, and systems at the nanometre scale (one meter consists of 1 billion nanometres). Nanomedicine, an offshoot of nanotechnology, refers to highly specific medical intervention at the molecular scale for curing disease or repairing damaged tissues, such as bone, muscle, or nerve119 Drug delivery can be defined as the process of releasing a bioactive agent at a specific site, at a specific rate using a suitable carrier.

Drug delivery system = Drug + Carrier120

Many conventional drugs have a poor solubility, low bioavailability, and they can be quickly cleared in the body by the reticuloendothelial system. Moreover, drug resistance at the target level owing to physiological barriers or cellular mechanisms is also encountered. Furthermore, the efficacy of different drugs, such as chemotherapeutical agents, is often limited by dose dependent side effects. Anticancer drugs, which usually have large volume of distribution, are toxic to both normal and cancer cells121 Today, most harmful side effects of treatments such as chemotherapy are a result of drug delivery methods that do not pin point their intended target cells accurately119 Therefore, precise drug release into highly specified target involves miniaturizing the delivery systems to become much smaller than their targets, ensuring easy and effective dissolution of the drug. Recent studies show nanotechnology based drug delivery systems have fulfilled this lacunae and greatly improved the performance of the currently available drugs to a great extent.

An ideal drug delivery vehicle would be targetable not just to specific tissues or organs, but to individual cell addresses within a tissue or organ. This ideal

vehicle would be biocompatible and virtually 100% reliable, with all drug molecules being delivered only to the desired target cells and none being delivered elsewhere so that unwanted side effects are eliminated.

The primary goals of nano-drug delivery system include:

* More specific drug targeting and delivery
* Reduction in toxicity while maintaining therapeutic effects
* Greater safety and biocompatibility
* Faster development of new safe medicines

The materials employed in the fabrication of nanostructures determine the type of nanostructures obtained and these nanostructures, in turn, determine the different properties obtained and the release characteristics of incorporated drugs. They are as follows122:

* + Polymeric nanoparticles
  + Liposomes
  + Dendrimers
  + Solid lipid nanocarriers
  + Polymeric micelles
  + Nanocapsules
  + Nanoemulsions
  + Ceramic nanoparticles
  + Metallic nanoparticles
  + Carbon nanoparticles

### APPLICATIONS OF NANODRUG DELIVERY SYSTEMS IN DENTISTRY-

To improve the understanding of subject, the applications in dentistry can be classified based on different categories as follows: Based on the type of drug delivery system

1. Nano drugs as their own carriers
   1. Caries control and tooth remineralisation
   2. Root canal disinfection
2. Nano drugs with nano carriers
   1. Dental caries vaccine
   2. Management of oral biofilm
   3. Dentin hypersensitivity
   4. Infection control
   5. Tissue engineering
   6. Local anaesthesia
   7. Cancer therapy
3. Nano drugs with other carriers
   1. Management of oral biofilm
   2. Dentin hypersensitivity
4. Drugs with nanocarriers
   1. Periodontal infections

### Based on the route of administration

1. Local route

a. Topical

* Caries control and tooth remineralisation
* Management of oral biofilm
* Dentin hypersensitivity
* Root canal disinfection
* Local anaesthesia

1. Systemic
   * Oral Infection control
   * Nasal
   * Dental caries vaccine
   * Injectable
   * Local anaesthesia
   * Oral cancer therapy

### ROOT CANAL DISINFECTION

The treatment of an infected root canal involves disinfection of the root canal system by a chemo-mechanical approach as well as inter-appointment medication. Nevertheless, microorganisms are known to resist conventional disinfection procedures after root canal treatment .The inability to completely disinfect root canal system has been attributed to the anatomic complexities of the root canal system and the structure of the dentin. Antibacterial nanoparticulates are found to have higher antibacterial activity than conventional antibacterial powders. This is because of the higher surface area and charge density of nanoparticulates, which enable them to achieve a greater degree of interaction with the negatively charged surface of bacterial

cells resulting in the leakage of intracellular components and cell death. Moreover these nanoparticles can be delivered into complex anatomical spaces due to their small size.

CS nanoparticles have been shown to provide a significant improvement in the root canal disinfection by directly eliminating the residual adherent and non-adherent bacteria, which, in turn, would prevent bacterial recolonization and biofilm formation as well as increasing the diffusion of antibacterial components from the root canal sealers. BAG of the SiO2-Na2O-CaO-P2O system has some antimicrobial activity when suspended in aqueous solutions via the release of their ionic compounds over time. The release of Na+ and Ca2+ ions, and the incorporation of H3O+ protons into the corroding glass result in a high pH environment which is not well-tolerated by microbiota. In addition, the release of silica has been linked to the antibacterial effect. The shift to nanosized BAG materials turns the environment more alkaline, and consequently has a better antimicrobial effect than the currently available micron sized BAG. These are potentially interesting materials for the treatment of necrotic root canals.

Ultrasound is applied in dentistry for the mechanical debridement of plaque and calculus. Studies have shown that bacteria can penetrate into dentinal tubules, and the depth of penetration varies from 300 mm to 1,500 mm 123,124. Unfortunately, the bacteria within the dentinal tubules are inaccessible to the conventional root canal irrigants, medicaments, and sealers because they have limited penetrability into the dentinal tubules. Although the application of ultrasound produced better results compared with syringe irrigation in cleaning and delivering irrigants into the anatomic complexities, ultrasonic irrigation did not debride the root canal system completely. Various studies have shown that high-intensity focused ultrasound (HIFU) is applied clinically to generate collapsing cavitation bubbles in fluids and tissues, which collapses with high-speed jets that can be used for drug delivery.

**CONCLUSION**

Endodontists have frequently boasted that they can do much of their work blindfolded simply because there is ‘‘nothing to see.’’ The truth is that there is a great deal to see with the right tools. In the last 15 years, for nonsurgical and surgical endodontics, there has been an explosion in the development of new technologies, instruments, and materials. These developments have improved the precision with which endodontics is performed. These advances have enabled clinicians to complete procedures that were once considered impossible or that could be performed only by talented or lucky clinicians.

Endodontics is a challenging and rewarding profession. With the right systems, team training, and leadership skills, endodontists can achieve their vision and create a highly successful practice.

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