ENDODONTIC REBOOT

Part Two

Bioactive materials are on the threshold of mainstream endodontics

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"Two roads diverged in a wood,
and I took the one less traveled by,
And that has made all the difference."
–Robert Frost

Three-dimensional "root filing" is unattainable with the materials used since the late 1800s. Gutta-percha has been and still is the core material of choice; however, even with the essential inclusion of a sealer, degradation and dissolution of both the gutta-percha core and the sealer will obviate long-term successful treatment outcomes.[1]

This article takes a critical look at past and present methods for root filling. The clinician's axiom of choice is to no longer persist with materials that fail to obtain permanent sealing of the root canal due to leakage from the oral cavity or, to effect a paradigm shift to a root filling protocol using bioactive bioceramic materials (Figs. 1a–1c).

Objectives of root filling

Currently, it is not possible to effect optimal sterilization of the root canal space, nor can biofilms be completely eradicated from the interfacial dentin. Thus, the aim involves three basic requirements from a root filling:

1. Stop coronal leakage after the root canal is filled and the final restoration placed.
2. Entomb surviving microflora in the interfacial dentin so that they cannot reassert their presence and communicate with the periradicular tissues.
3. Prevent influx of periapical fluids to provide nutrients for residual microflora in the root canal space.[2]

Lateral- and carrier-based obturation

Many in vitro, in vivo and clinical outcome studies have been performed primarily on single cone or lateral condensation techniques. It is apparent that they fail in their primary function of sealing the root canal space long term.[3–4]

Sabeti et al found no diffence in the outcome when a canal was root-filled compared to left empty. This study and others emphasize the poor quality of our current root filling techniques and the importance of the coronal restoration for successful root canal treatment outcomes.[5–6]

A study by Gihooly et al showed that multiphase gutta-percha obturation had significantly less apical dye leakage than lateral condensation in curved canals ($P < 0.05$).[7] Success based on degree of density is not the issue as gutta-percha does not bond to dentin. Sealer remains the dominant concern re: leakage over the long term.

Fig. 2 shows that when tested in an in vitro model, microbes will permeate the length of the canal space in two hours if only gutta-percha is present in the canal without

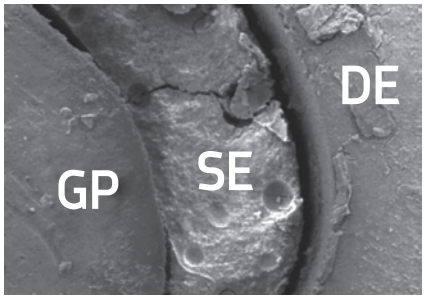
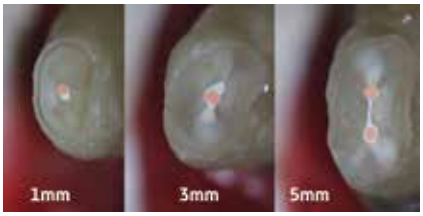
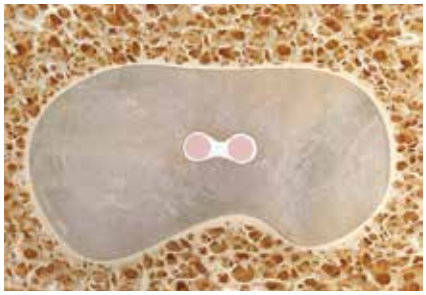


Fig 1a. *SEM of cut root filled with gutta-percha and AH Plus sealer. Note the gap between the gutta-percha (GP) and sealer (SE). (Courtesy of Dr. Eldeniz, AU.)*





Figs 1b (top) and 1c (above). *Image shows molar roots filled with bioceramic sealer cut at different distances from the apex. A single gutta-percha point is used as a cold plugger to create hydraulic pressure that moves the sealer to the apical pulp stump and fills any irregularities in the root canal space.*

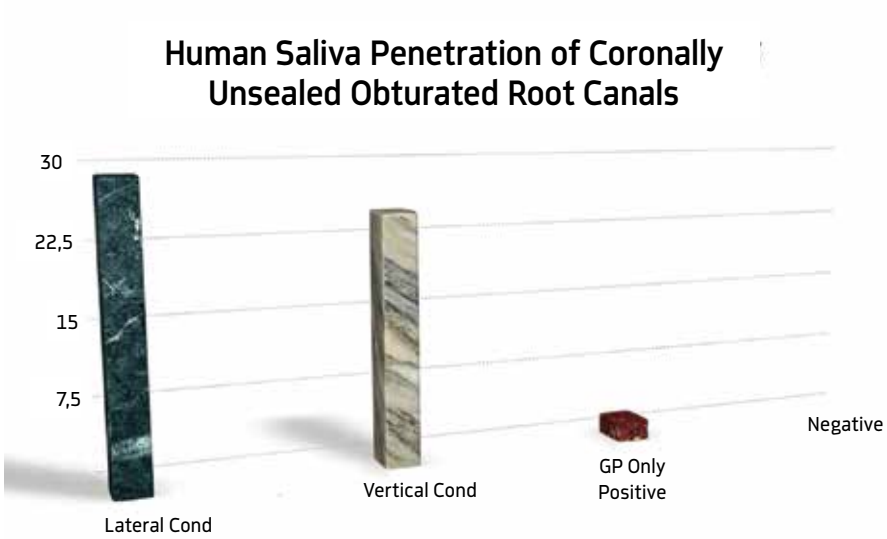


Fig 2. *In vitro evaluation of saliva penetration of root canals. Note that the seal achieved with gutta-percha alone is indistinguishable from the negative control. (from Khayat et al).*

Bioceramics are ideal for use in endodontics as they are not affected by moisture or blood contamination and, therefore, technique sensitivity is not an issue unlike most other sealers where moisture negates their performance.

sealer. The leakage can be delayed for up to 30 days with the use of sealer. Sealers are the materials in root canal filling that provide whatever resistance to leakage is achieved. Traditional sealers generally shrink on setting and wash out in the presence of tissue fluids[8–9](Fig. 3).

Results on the GuttaCore carrier-based system in combination with root canal sealer do not improve the microleakage resistance compared with Thermafil/Topseal filling and the Continuous Wave compaction technique.[10]

Gutta-percha, regardless of how it is biochemically reconstituted or introduced into the root canal space, is not an effective barrier to microbes. Furthermore, the volume of sealer is the weak link in the chain of success; volume must be minimized by the density of the core/filler regardless of the technique used. With the new array of equipment for identifying, shaping and cleaning of the root canal space, reliance on ineffective materials and techniques mandate a paradigm shift in root filling.

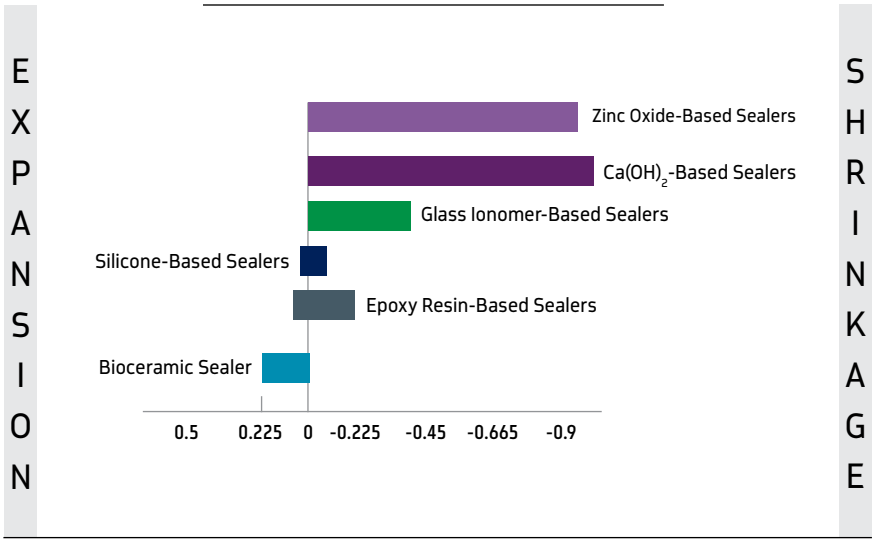


Fig 3. Table of expansion/shrinkage of popular sealers. Silicone and epoxy resin sealers expand slightly before shrinking. Note that by contrast, bioceramic sealer expands slightly on setting but does not shrink.

The Schilderian Epoch

Dr. Schilder's transgressive articles, "Vertical Compaction of Warm Gutta-Percha" and "Filling Canals in Three Dimensions," addressed technical adjustments to traditional obturation techniques that enabled gutta-percha to replicate the microstructural anatomy of the root canal space to a demonstrably greater degree than any previous technique.[11–12]

Despite the enhanced rheology, gutta-percha neither adhered to nor penetrated the interfacial dentin and it was sealer that was integral to achieving a positive treatment outcome, albeit short-lived. Schilder and Goodman[13] established the hypothesis that a warm vertical condensation technique pushed a greater volume of filler material into the apical space and theoretically the material would not shrink on cooling; however, regardless of enhanced gravitometrics, the leakage studies on gutta-percha alone and gutta-percha and sealer and their inability to create an impervious apical seal are repeatedly demonstrated in the literature.[14]

Microfractures are a complication of any instrumentation technique that requires significant preparation of the coronal portion of the canal to place a plugger/condenser (heated or otherwise) within 4mm of the working length. Furthermore, thinning of the root dentin by "imprinting a file size to accommodate a filling technique" will proportionally weaken the tooth, leaving a root susceptible to fracture.[15–16]

The future of bioceramic nanotechnology

Bioceramic materials include alumina, zirconia, bioactive glass, hydroxyapatite and resorbable calcium phosphates.[17–19] They are used as joint or tissue replacements in both

Hydration Reactions (A,B)

$$A\text{-}2[3CaO{\cdot}SiO_2] + 6H_2O \rightarrow 3CaO{\cdot}2SiO_2{\cdot}3H_2O + 3Ca(OH)_2$$

$$B\text{-}2[2CaO{\cdot}SiO_2] + 4H_2O \rightarrow 3CaO{\cdot}2SiO_2{\cdot}3H_2O + Ca(OH)_2$$

Fig 4a. *Chemistry associated with the hydration reaction of bioceramic material (calcium silicates) with water (moisture present in canal and tubuli) creates calcium silicate hydrate and calcium hydroxide.*

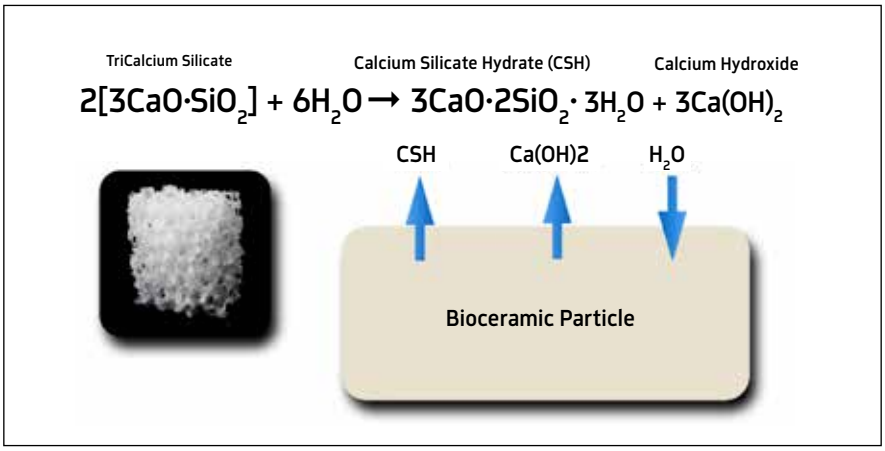


Fig 4b. *Precipitation reaction of the bioceramic (calcium phosphate). The hydroxyapatite co-precipitated within the calcium silicate hydrate phase produces a composite-like structure, reinforcing the set cement.*

Precipitation Reaction

$$C\text{-}7Ca(OH)_2 + 3Ca(H_2PO4)_2 \rightarrow Ca_{10}(PO4)_6(OH)_2 + 12H_2O$$

Figs 4c. *The bioactivity of the calcium-silicate-based materials has been shown to produce mineralization within the subjacent dentin substrate, extending deep within the tissues.*

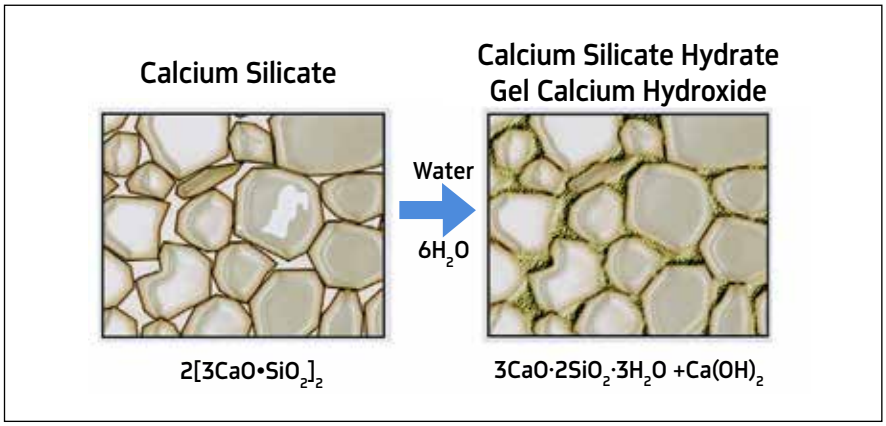


Fig 4d. *Setting reaction of the hydrated materials; a cementitous phase that is rich in calcium and silicon and a radiopacifying material is produced.*

medicine and dentistry as they are chemically and dimensionally stable, biocompatible and osteoconductive.

The properties, in addition to being non-corrosive, are categorized as:

- Bioinert—non-interactive with biological systems.
- Bioactive—durable tissues that can undergo interfacial interactions with surrounding tissue.
- Biodegradable, soluble or resorbable—eventually being replaced or are incorporated into tissues.

Bioceramics are ideal for use in endodontics as they are not affected by moisture or blood contamination and, therefore, technique sensitivity is not an issue unlike most other sealers where moisture negates their performance.[20]

Being that they are hydrophilic, residual moisture in the canal and dentinal tubuli are biochemically a positive factor. In the context of creating an impervious seal, they are dimensionally stable and expand slightly on setting, ensuring a long-term seal due to the hydration reaction forming calcium hydroxide and later dissociation into calcium and hydroxyl ions[21–22] (Figs. 4a, 4b).

When setting, the pH of the bioceramic is above 12, which is due to a hydration reaction forming calcium hydroxide and later dissociation into calcium and hydroxyl ions (Figs. 4c, 4d), which may explain the antibacterial properties of the bioceramic. The release of calcium hydroxide and its interaction with phosphates on contact with tissue fluids forms hydroxyapatite. This may explain the osteo-conductive potential of the material. Bioceramics are seen as today's material of choice for pulp capping, pulpotomy, perforation repair, root-end filling and obturation of immature teeth with unformed apices.[23]

A scientific paradigm shift in root filling

Premixed bioceramic sealer is composed of dicalcium and tricalcium silicate, calcium phosphates (monobasic), colloidal silica, water-free thickeners and calcium hydroxide in combination with radiopacifiers

(zirconium oxide) and marketed in the U.S. as EndoSequence BC Sealer, (Brasseler USA, Savannah, Georgia). The sealer is similar in chemical composition (calcium silicates, zirconium oxide, tantalum oxide, calcium phosphate monobasic and fillers). They are hydrophilic, insoluble, radiopaque, aluminum-free, high pH, and require moisture to set. The singular most important feature is the gap between the sealer and the core is eliminated and as such the sealing of the root filling is optimally potentiated.[24–25]

The properties of the bioceramic sealer enact changes in the root filling procedure:

1. Being hydrophilic, naturally occurring moisture in the canal and tubuli is an advantage.
2. When unset, the bioceramic sealer has a pH above 12, thus its antibacterial properties are similar to calcium hydroxide.[25] Setting is dependent on physiologic moisture in the canal; therefore it will set at different rates in different environments, but since it is a high pH, any delay in setting can arguably be beneficial.
3. The sealer does not shrink but expands slightly, and it is insoluble in tissue fluids.[26]

The afore-referenced properties should change the enduring—albeit antiquated—rule that the core material in root fillings should mask the deficiencies of the sealer by keeping it as thin as possible. In theory, the need for any core/filler material should prove debatable if it were possible to fill the canal homogeneously with bioceramic sealer. As it stands, the gutta-percha is used to deliver the bioceramic sealer through hydraulic condensation and the sealer can be the main component of the root filling. The gutta-percha is used primarily as the delivery device (plugger) to allow cold hydraulic movement of the sealer into the irregularities of the root canal and accessory canals. In addition, it will act as a pathway for post preparation and retreatment.

As the root filling paradigm shifts to bioceramic sealers, the practitioner can execute a biominimalistic antimicrobial protocol for root canal treatment leaving a thicker and stronger root. When the taper is not excessive and the gutta-percha point is used as a condenser to move the sealer into the canal irregularities and accessory canals, a radiographic picture consistent with the classic vertical condensation technique is seen (Figs. 5a, 5b).

Technique troubleshooting

As the EndoSequence BC sealer is premixed, storage should be at room (ambient) temperature. As discussed previously, unlike traditional sealers, the setting reaction of bioceramic sealers is initiated by moisture in the canal, therefore refrigeration is to be avoided.[27] The booster tip of the XP-3D Shaper provides a unique apical seat, which will minimize sealer extrusion.

Fig 5a. *Radiograph of a root filled tooth showing EndoSequence BC Sealer hydraulically moved by the gutta-percha point apical terminus. Note that the cold hydraulic technique results in lateral canal "puffs" similar to the warm vertical condensation technique. (Courtesy of Dr. Gilberto Debelian)*

Fig 5b. *Molar filled using the cold hydraulic technique. Note the biominimalistic shaping of the coronal and middle third of the canals resulting from the use of the XP-3D Shaper and Finisher. (Courtesy of Dr. Frank Setzer)*

The amount of sealer introduced into the canal should be controlled so that only a modest amount is expressed and expression of surplus is not introduced in the periapical region. The syringe delivery system should not be positioned greater than the interface of the coronal and middle third of the root canal. The bioceramic sealer flows easier than AH Plus and other sealers due to its particle size (< 2µ) and this mandates a degree of practice.

A nano-coated gutta-percha cone with a laser-verified tip for accuracy is mated to the canal preparation. Its purpose, unlike traditional compaction techniques, where the volume of gutta-percha needs to optimal to minimize the volume of sealer, is used to deliver the bioceramic sealer to the apical seat without heat or pressure; the bioceramic being bioactive and adherent to the interfacial dentin creates a true impervious apical seal.

Depending on the shape of the apical region (circular or ovoid) and the intimacy of fit of the master nano-coated gutta-percha cone, the master file used to apically gauge

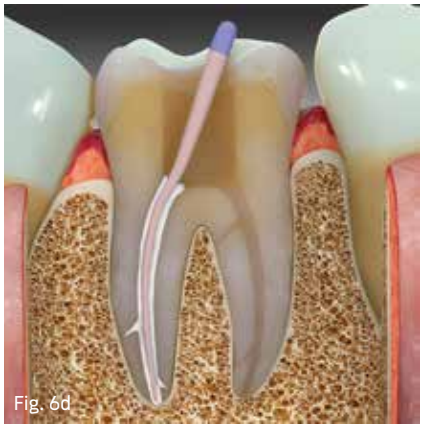


Fig 6a. *After irrigation, the canal is dried and a suitably tapered gutta-percha cone is fit to the apical terminus.*
Fig 6b. *An aliquot of EndoSequence BC sealer is injected into the coronal and middle third of the root canal space using the tips designed for the sealer cartridge.*
Fig 6c. *The SensiPast lentulo spiral used 2–3mm short of the apical terminus to bring the bioceramic sealer along the length of the root canal space.*
Fig 6d. *Insertion of the prefit gutta-percha cone coated with nano-ceramic bioceramic particles will hydraulically push the sealer to the apical terminus.*
Fig 6e. *The gutta-percha and sealer are removed to create footings for the subfloor used in the inlay/onlay rehabilitation or to create a post channel where required.*

and size can be coated with sealer and introduced in a counter-clockwise manner to deposit the sealer at the apical terminus. The master cone coated with a thin layer of sealer is then slowly introduced to the apical seat to avoid trapping air or excess sealer and preventing it seating fully. The gutta-percha handle is severed with heat at the orifice or below for a canal footing or a post space (Figs. 6a–6d).

All variables in an equation are interdependent. In the case of endodontic success, each procedural event is accountable for the positive treatment outcome; however, regardless of its importance, if a concomitant event doesn't provide a suitable biologic conclusion, failure ensues. The shrinkage and instability of root canal sealers have mandated their use in thin layers and necessitated techniques to ensure this requirement.

Biominimalism in canal space preparation requires a filling material that replicates the internal anatomy of the root canal space, adheres to interfacial dentin and creates an impervious, irreversible seal at all portals of exit.

We are almost there; the last mile of this endodontic marathon will be to obviate entirely the need for a core point of any formulation. ■

References

1. *Gutmann JL. Clinical, radiographic and histologic perspectives on success and failure in endodontics. Dent Clin North Am 1992;36:379-381*
2. *Sundqvist G, Figdor. Endodontic treatment of apical periodontitis. In: Ørstavik D, Pitt Ford TR, eds. Essential Endodontology. , Prevention and Treatment of Apical Periodontitis. Oxford: Blackwell:1998:242-277*
3. *Geurtsen W, Leyhausen G. Biological aspects of root canal filling materials—histocompatibility, cytotoxicity and mutagenicity. Clin Oral Investig 1997;1:5–11*
4. *Ørstavik D. Antibacterial properties of root canal sealers cements and pastes. Int Endod J 1981; 14:125–133*
5. *Sabeti M, et al. Healing of apical periodontitis after endodontic treatment with and without obturation in dogs. J Endodon 2006;36:628-633*
6. *Ray HA, Trope M. Periapical status of endodontically treated teeth in relation to the technical quality of the root filling and the coronal restoration.Int Endod J. 1995 Jan;28(1):12-8.*
7. *Gilhooly RM, Hayes SJ, Bryant ST, Dummer PM. Comparison of cold lateral condensation and a warm multiphase gutta-percha technique for obturating curved root canals. Int Endod J. September 2000;33(5):415-20*
8. *Ørstavik D, Nordahl I, Tibbels JE. Dimensional change following setting of root canal sealer materials. Dent Mater 2001;17:512-519*
9. *Marin-Bauza et al. Physicochemical properties of endodontic sealers of different bases J Appl Oral Sci 2012;20:455-461*
10. *Schäfer E, Schrenker C, Zupanc J, Bürklein S. Percentage of Gutta-percha Filled Areas in Canals Obturated with Cross-linked Gutta-percha Core-carrier Systems, Single-Cone and Lateral Compaction Technique. J Endodon Feb 2016;42(2):296-298*
11. *Schilder H. Filling root canals in three dimensions. J Endo April 2006;32(4):281-90*
12. *Schilder H. Vertical compaction of warm gutta-percha. Dental Clinics of North America 1967;723-44*
13. *Schilder H, Goodman A, Aldrich W. The thermomechanical properties of gutta-percha. I. The compressibility of gutta-percha. Oral Surg Oral Med Oral Pathol 1974;37:946–53*
14. *Goodman A, Schilder H, Aldrich W. The thermomechanical properties of gutta-percha. II. The history and molecular chemistry of gutta-percha. Oral Surg Oral Med Oral Pathol 1974;37:954–61*
15. *Sathorn C, Palamara J, Messer H. A comparison of the effects of two canal preparation techniques on root fracture susceptibility and fracture pattern. J Endod April 2005;31(4): 283–287*
16. *Pedullà E, Genovesi F, Rapisarda S, et al. Effects of 6 Single-File Systems on Dentinal Crack Formation. J Endod. 2017 Jan 25 in press*
17. *Jefferies S. Bioactive and biomimetic restorative materials: a comprehensive review. Part I. J Esthet Restor Dent Jan/Feb2014;26(1):14-26*
18. *Hench L. Bioceramics: from concept to clinic. J Am Ceram Soc July 1991;74(7):1487-1510*
19. *Best SM, et al. Bioceramics: Past, present and for the future. J Euro Ceram Soc 2008;28:1319-27*
20. *Kossler W, Fuchs J (ed). Bioceramics: Properties, Preparation and Applications. Nova Science Publishers 2009*
21. *Richardson IG. The calcium silicate hydrates. Cem Conc Res 2008;38:137-158*
22. *Koch A, Brave D, Nasseh AA. A review of bioceramic technology in endodontics. Roots 2012;(4):6-12*
23. *Tran XV et al. Effect of a calcium-silicate-based restorative cement on pulp repair. J Dent Res 2012;91:1166-1171*
24. *Hulbert SF, et al. Ceramics in Clinical applications past present and future. Proc World Congress-High Tech Ceramics:189-213*
25. *Nekoofar MH, Stone DF, Dummer PM. The effect of blood contamination on the compressive strength and surface microstructure of mineral trioxide aggregate. Int Endod J 2010;43:782-7921*
26. *Gandolfi MG, Iacono F, Agee K, Siboni F, et al. Setting time and expansion in different soaking media of experimental accelerated calcium-silicate cements and ProRoot MTA. Oral Surg Oral Med Oral Pathol Oral Radiol Endod December 2009;108(6):e39-45*
27. *Koch K, Brave D. Bioceramic technology – the game changer in endodontics. Endodontic Practice US. April 2009;12:7-11*