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REVIEW ARTICLE

Evolution of root canal sealers: An insight story

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ABSTRACT

Attainment of ideal root canal treatment comprises various essential factors such as proper instrumentation, biomechanical preparation, obturation, and ultimately depending upon the case, post-endodontic restoration. Main objective of the treatment is to get absolute rid of microbial entity and prevent any future predilection of re-infection. In order to achieve that, proper seal is required to cut down any chance of proliferation of bacteria and future occurrence of any pathology. Although gutta-percha has been the standard obturating material used in root canal treatment, it does not reinforce endodontically treated roots owing to its inability to achieve an impervious seal along the dentinal walls of the root canal. Gutta-percha does not from a monoblock even with the use of a resin-based sealer such as AH Plus because the sealer does not bind to gutta-percha. As a result, a monoblock is formed (consisting of Resilon core material, Resin sealer, bonding agent/primer, and dentin). Another reason of Resilon being a better obturating material could be that the removal of smear layer by ethylenediaminetetraacetic acid (EDTA) after biomechanical preparation may have allowed the root canal filling material and root canal sealers to contact the canal wall and penetrate in the dentinal tubules, which may increase the strength of roots. New silicone-based sealers like Roekoseal automix and the most recent GuttaFlow have some affirmative results regarding solubility and biocompatibility, as compared to other sealers. Methacrylate resin–based sealers and mineral trioxide aggregate (MTA)-based sealers have opened a new horizon for sealers.

Key words
Biocompatibility, contemporary sealers, cytotoxicity, leakage, monoblock

INRODUCTION

Accomplishment of ideal root canal treatment is attributed to various essential factors such as proper instrumentation, biomechanical preparation, obturation, and ultimately depending upon the case post-endodontic restoration. The pertinent aim of this treatment is to do away with the microbial entity and any future predilection of re-infection. In order to achieve this, proper seal is required to denigrate any chance of proliferation of bacteria and future occurrence of any pathology. Sealer along with solid obturating material acts synergistically to create hermetic seal.[1,2]

The quality of the seal obtained with gutta-percha (GP) and conventional zinc oxide eugenol (ZOE) sealers is quite far from being perfect.[3,4] Also, despite its multiple strong points, GP and conventional sealer combination still has its own shortcomings, like its inability to strengthen root, as it does not adhere to dentin, inability to control microleakage, and the solubility of sealer makes prognosis dilemmatic and un-assuring. Although few materials are capable enough to swap GP on multiple parameters, research continues to find alternatives that may seal better and mechanically reinforce compromised roots by forming monoblock, which has been suggested to reduce bacterial ingress pathways and strengthen the root to some extent.[5,6,10] Hence, several new resin cement sealants have been developed to be used instead of ZOE, thereby improving the root canal seal and imparting it more strength as compared to the conventional materials.[3,4] These include silicon-based sealers which are well tolerated by tissues, have low water sorption, and have a potential of forming monoblock, thus reinforcing root canal,[7] epoxy resin–based sealers with the possibility of adhesion to dentin and with lower rates of water solubility,[7,8] and mineral trioxide aggregate (MTA)-based sealers which have the predilection toward mineralization along with all the viable properties of orthodox sealers. Nevertheless, resin-based and silicon-based materials are also soluble, which may endanger a proper seal,

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although the solubility of resin-based materials is usually lesser than that of ZOE (which is reported as between 1% and 7%)[9] and does not exceed a maximum weight loss of 3% within 24 h of distilled water storage (in accordance with the standards for Root Canal treatment sealer (R Cl T).[7,8] Accordingly, availability of so many sealers makes it impossible for the clinician to decide what to avail and when. So, the purpose of the article is to create awareness about the different types of sealers and their pros and cons. Every manufacturer claims its product to be the ideal one, but only the clinical results can give the affirmation or negation of that particular sealer. Till date, none of the sealers has proved to be the ideal except a few which can come closer to being one. The objectives of this review are to delineate the behavior of contemporary sealers and juxtapose it with that of conventional sealers and their future clinical use based on all the parameters required for ascendancy.

CONVENTIONAL ROOT CANAL SEALER

Early sealers were modified zinc oxide–eugenol (ZOE) cements based on Grossman or Rickerts's formula that were widely used throughout the world. Unlike the resin-based sealers, setting reaction of ZOE-based sealers is a chelation reaction occurring between eugenol and the zinc ion of the zinc oxide. This reaction might also occur with the zinc oxide phase of GP along with the calcium ions of dentin. This might explain the decreased setting shrinkage associated with the ZOE-based sealers.[11] Components are given in Table 1.1.

Michaud *et al.*[12] evaluated the three-dimensional expansion of GP at various powder/liquid ratios of Pulp Canal Sealer extended working time (EWT) (ZOE-based sealer) by using spiral (helical) computed tomography (SCT). They concluded that increasing the ratio of eugenol in sealer resulted in volumetric increase of GP [Figure 1].[13] It is cerebrated that the free eugenol component of freshly mixed ZOE sealer can seep out and cause various cytotoxic effects on human gingival fibroblasts, periodontal ligament (PDL) cells, and osteoblast-like cells.[13,14] However, Haseih *et al.*[15] reported that leakage of eugenol into periapical tissues is very low, and it dramatically decreases over time.

Sealing properties of ZOE ZnOE sealers were inferior in comparison to other sealers due to the relatively high solubility of the ZOE sealer; so, adhesion between GP and ZOE is weak [Figure 2].[16] Eugenol is cytotoxic and the same has been shown frequently for ZOE with different cell culture systems, especially after mixing, but also in a set state. Even higher cytotoxicity was observed with formaldehyde-containing ZOE sealers, which were classified as highly/extremely cytotoxic.[17] An ZOE sealer in the pulp chamber disinfected the dental tubules to a depth of 250 μm[18] and had a good antimicrobial property compared to other sealers.[19,20]

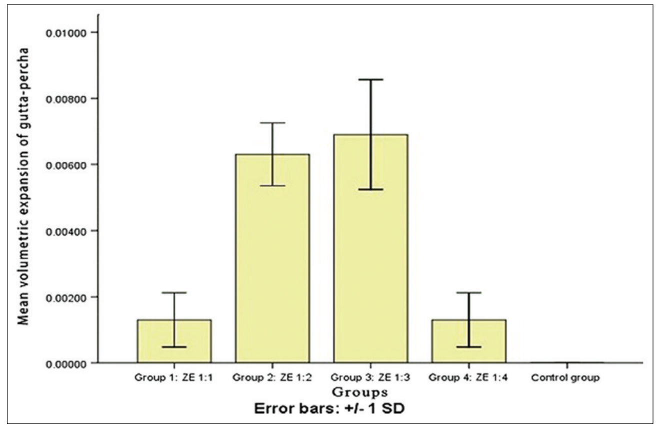

Figure 1: Effects of altered powder/liquid ratios on volumetric change of gutta-percha at the end of 1-month interval. Control group (no sealer group) exhibited no visible expansion. Significant difference ($P<0.05$) between ZE 1:2 and ZE 1:3 groups when compared with ZE 1:1 and ZE 1:4 groups. SD, standard deviation (courtesy: Chandrasekhar *et al.* 2011)

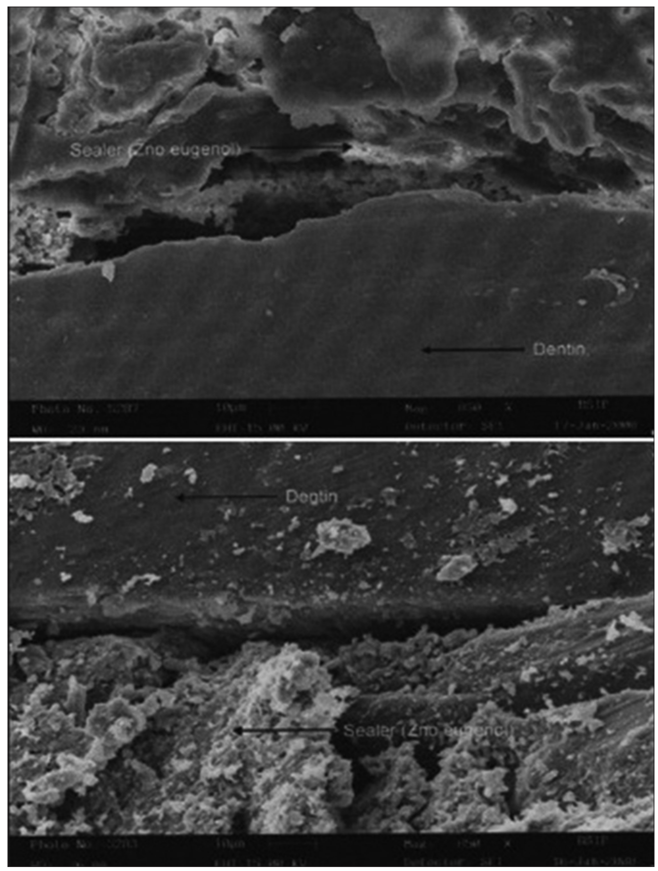

Figure 2: The adhesion between gutta-percha and zinc oxide eugenol is weak, and hence a gap remains (courtesy: Upadhyay *et al.* 2011)

CONTEMPORARY SEALERS

- AH Plus
- GuttaFlow
- MTA-based sealers
- EndoSequence bioceramic sealer
- Methacrylate-based resin sealer

Table 1: List of the root canal sealers, their composition, manufacturer, advantages and disadvantages

Root canal sealers	Brand	Composition of sealers	Manufacturer	Advantages	Disadvantages
1.1 Zinc oxide eugenol	Roth sealer Kerr PCS Procoseal Endomethasone	Powder: Zinc oxide (42%) Staybelite resin (27%) Bismuth subcarbonate (15%) Barium sulfate (15%) Sodium borate, anhydrous (1%) Liquid: Eugenol (4-allyl-2-methoxyphenol)	Roth Inc., Chicago, IL, USA Kerr PCS, silver Kerr, Romulus, MI, USA ProcoSol, Den-tal-ez, Lancaster, PA, USA Septodont, Saint-Maur des Fosse's, France	1. Lowest shrinkage (0.14%) compared to resin based sealers.[16] 2. Long lasting antimicrobial property. ZOE sealers have demonstrated antimicrobial properties on a variety of microorganisms, including Enterococcus faecalis suspensions and anaerobic bacteria even 7 days after mixing.[20] 3. ZOE-based sealers are easy to handle. 4. The radiopacity of different ZOE sealers was 5-7.97 mm Al and thus can be regarded as sufficient.[21] 5. Powder/Liquid ratio of 1:3 causes volumetric expansion of gutta percha which further seals the canal.[12] 6. Dimensional changes is very less 0.419±0.298 as compared to other sealers.[16]	1. Several studies showed apical leakage around ZOE sealers that increased with storage time (measured up to 2 years) in thick layers more than in thin layers. Sealing properties of ZOE sealers were inferior in comparison to other sealers (resin or calcium hydroxide sealers).[22] 2. Formaldehyde, which is released from certain ZOE sealers, is also a known allergen which were classified as highly/extremely cytotoxic. Formaldehyde containing sealers suggest permanent damage of the nerve *in vivo*.[23] 3. Eugenol inhibited nerve conductance *in vitro* in experiments with different nerve tissues.[24] 4. Highest solubility as compared to other contemporary sealer thus making more prone to cause microleakage 2,426±0,733 though within the within the limits of ISO standards (weight loss-3% of mass).[17]
1.2 Epoxy resin based sealer	AH Plus AH26 TopSeal 2-Seal	For AHPlus Epoxide paste Diepoxide Calcium tungstate Zirconium oxide Aerosil Pigment Amine paste 1-adamantane amine N, N′-dibenzyl-5-oxa-nonandiamine-1,9 TCD-Diamine Calcium tungstate Zirconium oxide Aerosil Silicone oil For AH26 AH 26, powder: Bismuth oxide, Methenamine, Silver, Titanium dioxide	Dentsply Maillefer, Ballaigues, Switzerland Dentsply Maillefer, Ballaigues, Switzerland] VDW, Endodontic Synergy, Munchen, Germany	1. Radiopacity-13. 6 mm of Al of AH Plus, and AH-26 has 9.3 mm of Al.[25] 2. Dimensional stability-polymerisation shrinkage of AH Plus is 1.76 V% and AH-26 is 1.46 V%.[25] 3. Solubility is very less for AH Plus but for AH-26 it is more than Roekoseal and AH Plus.[25] 4. The linear expansion of AH Plus is very low (0.129±0.08) very less than other sealer.[25] 5. AH-26 and AH Plus is able to flow into the orifices of the dentinal tubules, which is the reason for the comparatively good adhesion of AH-26 to dentin.[25] 6. Handling properties are usually considered to be good. 7. Release of formaldehyde-Only a minimum release was observed for AH Plus (3.9 ppm).[29] 8. AH Plus produced slight inhibition on Streptococcus mutants at 20 days and on Actinomyces israelii at every time interval.[28]	1. AH-26 has harmful amount of formaldehyde release is 1347 ppm.[29] 2. Reversible acute inflammation of the oral mucosa after contact with the unset paste. In individual cases, local and systemic allergic reactions have been reported.[25] 3. Bisphenol A diglycidyl ether was identified as a mutagenic component of resin-based materials, which may also be cytotoxic.[25] 4. Epoxy resin-based sealers adhere better to the dentin walls, making their removal with rotary instruments difficult.[36] 5. Less fracture resistance when used with gutta percha as compared to Resilon/Realseal.[37] 6. With the epoxy-based sealer either no difference (shear) or lower bond strength in thin films was found, and appeared to result from numerous voids created during mixing.[38]

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Table 1: Continued

Root canal sealers	Brand	Composition of sealers	Manufacturer	Advantages	Disadvantages
		AH 26 silverfree, powder: Bismuth oxide, Methenamine AH 26 resin: Epoxy resin		9. Tissue compatibility-no genotoxicity and mutagenicity were revealed by AH Plus.[25] 10. Removability-If AH Plus is used in combination with gutta-percha points, the root canal fillings can be removed using conventional techniques for the removal of gutta-percha.[36] 11. 2-seal has lowest solubility followed by Topseal and AH26 has maximum solubility.[33]	
1.3 Silicone based sealer	RoekoSeal Gutta flow	Polydimethylsiloxane, silicone oil, zirconium oxide Polydimethylsiloxane, silicone oil, zirconium oxide, gutta-percha	Roeko/Colte`ne/Whaledent, Langenau, Germany	1. Gutta-Flow showed good spreadability* 2. Contains nanosilver which prevent further spread of bacteria* 3. Ease of handling* 4. Good adaptability* 5. Flowable cold filling system* 6. Two in one-combines sealer and gutta-percha* 7. Excellent flow properties* 8. Solubility is virtually zero* 9. Tight seal of the root canal* 10. Very good biocompatibility* 11. Optimum protection against re-infection* 12. Excellent radiopacity* *→[40] 13. Allows for precise post preparation 14. The included nano-silver can also have a preserving effect in the canal. The chemical type and concentration of the silver does not cause corrosion or color changes in the GuttaFlow.[41] 15. A gutta-percha containing silicone sealer expands slightly and thus leakage was reported to be less than for AH-26 with gutta-percha over a period of 12 months.[43] 16. The GuttaFlow and EndoSequence BC sealers have lower cytotoxicity than the AH Plus.[80] 17. RoekoSeal, which is considered as the initial form of GuttaFlow, was	1. Dentin surface treated only with EDTA showed high contact angle value, suggesting the poor wettability of GuttaFlow.[45] 2. The minimum requirement is 3 mm Al-equivalents, which may be on the low side considering that conventional gutta-percha points are about 6mm Al-equivalents.[21] 3. Inherent voids are present within the core root filling material.[41] 4. GuttaFlow does not adhere chemically to the dentin.[41] 5. Due to its viscosity, it is more likely to be extruded into the periapical tissue when placed under pressure.[46] 6. GuttaFlow does not exhibit chemical bonding to the canal wall.[41]

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Table 1: Continued

Root canal sealers	Brand	Composition of sealers	Manufacturer	Advantages	Disadvantages
				removed more easily from the canals than a resin-based sealer.[45]	
1.4 MTA based sealer	Endo-CPM-Sealer, MTA Obtura ProRoot Endo Sealer MTA fillapex	EGEO srl, Buenos Aires, Argentina Angelus, Londrina PR, Brazil Dentsply Maillefer, Ballaigues, Switzerland MTA-F; Angelus, Londrina, Brazil	50% MTA (SiO_2, K_2O, Al_2O_3, SO_3, CaO and Bi_2O_3-50% SiO_2-7%, $CaCO_3$-10%, Bi_2O_3-10%, $BaSO_4$-10%, propylene glycol alginate-1%, propylene glycol-1%, sodium citrate-1% calcium chloride-10%	1. Highly biocompatible.* 2. Stimulate mineralization.* 3. Encourage apatite-like crystalline deposits along the apical and middle thirds of canal walls.* *→[50] 4. These materials exhibited higher push-out strengths after storage.[57] 5. Fluoride-doped MTA demonstrated stable sealing up to 6 months and significantly better than conventional MTA sealers.[58] 6. It has an adequate calcium releasing property 7. Endo- CPM was also reported to have a similar or better sealing ability to resin-based sealers.[59] 8. ProRoot Endo Sealer demonstrated the superior sealing ability of this material comparable to resin-based sealers.[59] 9. After setting, the cytotoxicity of MTA-F decreases and the sealer presents suitable bioactivity to stimulate Hydroxyapatite crystal nucleation.[60] 10. MTA Fillapex yields an impressive, hermetic seal in which the MTA particles expand, preventing microinfiltration. And, MTA simultaneously releases free calcium ions [Ca^{2+}] to accelerate the healing process by stimulating the regeneration of the adjacent tissues.[64] 11. Endo-CPM sealer showed the highest values of bond strength to root dentin (8.265 MPa) ($P<.05$). The values of push-out test were similar for MTA Fillapex (2.041 MPa) and AH Plus (3.034 MPa.[61]	1. Do not bind to dentin and core material 2. MTA Fillapex had the lowest push-out bond values to root dentine compared with other sealers.[61] 3. MTA Fillapex® setting time, which has resin in its composition consequently reducing the medium alkalinisation hence less mineralisation then other MTA sealers.[71] 4. The alkalinity of MTA can theoretically weaken root dentin similar to the findings on calcium hydroxide.[69] 5. In cases of MTA-based materials extrusion outside the root canal is associated with severe pain felt by the patient.[82]

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Table 1: Continued

Root canal sealers	Brand	Composition of sealers	Manufacturer	Advantages	Disadvantages
1.5 Calcium-Silicate-Phosphate-based bioceramic Sealer	Endosequence/ iroot SP Iroot BP Bio aggregate	Brasseler USA, Savannah, GA; Innovative BioCeramix Inc., Vancouver, BC, Canada) Innovative BioCeramix Inc.	Tricalcium silicate, dicalcium silicate, calcium phosphates, colloidal silica, and calcium hydroxide zirconium oxide as the radiopacifier	1. Biocompatible and do not induce critical cytotoxic effects.[81] 2. Formation of a nano-composite network of gel-like calcium silicate hydrate intimately mixed with hydroxyapatite, bioceramic, and forms a hermetic seal when applied inside the root canal.* 3. Precipitates calcium phosphate on hydration with same strength as human bone 4. iRoot BP is non-mutagenic, does not cause an allergenic potential after multiple uses and has a good tolerance by subcutaneous tissue* 5. High alkalinity increases its mineralisation process also its bactericidal properties (pH 12.8)* 6. Hydrophilic, root canal hydration aids in the formation of calcium phosphate hence gives strength* 7. Low contact angle hence these features allow them to spread easily over the dentin walls of the root canal and to get inside and fill the lateral micro canals* 8. These new bioceramic sealers also form chemical bond with the canal's dentin walls. That is why no space is left between the sealer and dentin walls.* 9. They are also osseo-conductive 10. Very good radiopacity (3.8 mm of Al).[78] 11. Setting time is 3-4 hrs hence it gives ample amount of time for placement of root canal.* 12. Bioceramics do not shrink upon setting. In fact, they actually expand slightly upon completion of the setting process.* 13. Furthermore (and this is very important in endodontics), bioceramics will not result in a significant inflammatory response if an overfill occurs during the obturation process.[82]	1. Changes in environmental water content adversely affect the setting time and microhardness of EndoSequence BC Sealer.[81] 2. Conventional retreatment techniques are not able to fully remove Bioceramic sealer.[83]

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Table 1: Continued

Root canal sealers	Brand	Composition of sealers	Manufacturer	Advantages	Disadvantages
				14. Remarkable flowability of the BC Sealer. This is a result of its particle size and hydrophilicity. (27 mm).[82] 15. Bioceramic sealer has more fracture resistance then conventional sealer.[82] 16. When bioceramic-based sealers BioAggregate or iRoot SP are extruded, the pain is relatively small or totally absent.* *-[85]	
1.6 Methacrylate resin based sealer	Hydron-First generation EndoREZ-Second generation Realseal Epiphany-Third generation Fibrefill-Third generation Realseal SE Metaseal SE- Fourth generation Smartseal	Hydron technologies, Inc, Pompano Beach, FL Ultradent product inc, South Jordan UT SybronEndo, Orange, CA/Pentron Clinical technologies Pentron clinical technologies, Wallingford, CT SybronEndo, Orange, CA Parkell inc Smart seal (DRFP Ltd, Stamford, United Kingdom),	bisphenol-A-glycidyldimethacrylate (BisGMA), Ethoxylated BisGMA, urethanedimethacrylate (UDMA) and Hydrophilic difunctional methacrylates. Calcium hydroxide, barium sulfate, barium glass, and silica. The primer-a self-etch primer that contains sulfonic acid-terminated functional monomer, Hydroxyethylmethacrylate (HEMA), water and a polymerization initiator. Smartpoint, a radiopaque non-gutta-percha core with a radiolucent hydrophilic polymer coating (copolymer of vinylpyrrolidone and acrylonitrile, methyl methacrylate, or HEMA) and Smart paste, a radiolucent sealer that contains an active polymer	1. When used with resilon forms 'Monoblock' which further improves the seal.[68] 2. Realseal has greater root fracture resistance compared to AH Plus.[37] 3. Good radiopacity but less then AH Plus.[25] 4. Slow polymerization of the dual-curable sealers would improve the chance for the relief of shrinkage stress via resin flow.[104] 5. They showed that roots filled with Resilon/Epiphany exhibited significantly higher fracture load values than those filled with gutta-percha/AH-26 when the specimens were subjected to vertical loading forces.[100] 6. EndoREZ was found to be well-tolerated by connective tissues and bone tissue.[103,109] 7. Methacrylate resin–based sealers used with Resilon or gutta-percha were more effectively removed, with less remnant filling material than conventional sealer/gutta-percha combinations.[105] 8. Smartpoint expands only laterally on absorbing water from the tooth, adopting the canal shape. Smart paste also expands on hydration to form a perfect seal[106] 9. FibreFill R.C.S. is reported to have good sealing and adhesive properties to radicular dentin.[107]	1. Epiphany and metaseal is cytotoxic even after dilutions.[101] 2. Resilon/Epiphany (RealSeal)-filled canals also contained significantly more voids and gaps than those filled with gutta-percha and conventional sealers.[97] 3. Lower push-out strengths than gutta percha/conventional nonbonding sealer combinations.[130] 4. Greater C- factor causing more polymerisation shrinkage hence more gap formation and microleakage.[98] 5. The chemical coupling between contemporary methacrylate resin–based sealers to root filling materials is generally weak or insufficiently optimized.[98] 6. Creeping of incompletely polymerized resinous sealers, which results in failure along the sealer-dentin interface.[126] 7. Presence of residual monomers in the root canals.[127] 8. Epiphany in both freshly mixed and set conditions showed a severe to moderate cytotoxic effect, and its cytotoxicity actually increased with time, posing significant cytotoxic risks.[39,131] 9. Epiphany is insoluble in the solvents commonly used in dentistry. Thus, removal of resin sealers from fins, accessory canals, or canal isthmi remains a challenge.[91] 10. Solubility values for Epiphany and AH Plus were 3.41% but according to ADA it should be less than 3%.[25]

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Table 1: Continued

Root canal sealers	Brand	Composition of sealers	Manufacturer	Advantages	Disadvantages
				10. For methacrylate resin-based sealers, thin films had higher bond strength than thick.[38] 11. The chemical union between the polyisoprene component of the gutta-percha and the polybutadiene end of the EndoRez resin coating	11. Unreacted monomers, leachable monomers from the incompletely polymerized Smart paste sealer can leak through the apical foramen after water sorption and swelling and cause inadvertent harmful detrimental effects on the periodontal tissues.[132] 12. Diffusion of water into resin matrices might result in the rapid deterioration of the physical/mechanical properties of a resin, compromising the durability of resin-dentin bonds by hydrolysis and microcrack formation.[133]
				molecule appears to be stronger than the coupling between the methacrylate end of the molecule to the resin sealer.[93] 12. EndoRez showed increased intratubular penetration compared to AHPlus and Endo CPM- sealer.[63]	13. Decreased dentin thickness, lack of polymerization, or extended exposure times might increase the risk of cytotoxixity of HEMA significantly[134] 14. EndoREZ with a gutta-percha point into a dried root canal produces poor adaptation of the sealer to dentin with a lack of resin tag formation.[92] 15. Realseal has the potential to cause tooth staining as it is susceptible to enzymatic and alkaline hydrolysis.[99] 16. METAseal is found to be most cytotoxic when compared with AH Plus, Epiphany and EndoREZ.[108]
1.7 Calcium phosphate sealer	Capseal I Capseal II	Sankin Apetite Sealer; Sankin Kogyo, Tokyo, Japan	Powder: Tricalcium phosphate Dicalcium dihydrate Portland cement Zirconium oxide Liquid: Sodium phosphate solution	1. CAPSEAL I and II show less cytotoxicity and inflammatory mediators compared with other sealers and have the potential to promote bone regeneration as root canal sealers.[135] 2. CAPSEAL I and II facilitate the periapical dentoalveolar and alveolar healing by controlling cellular mediators from PDL cells and osteoblast differentiation of precursor cells.[136] 3. CAPSEAL I and II sealers were well-adapted to the canal wall and infiltrated into the dentinal tubules.[139]	1. Fracture resistance is yet to evaluate.[137] 2. CPS-1 sealer is not biocompatible.[138]

- Calcium phosphate–based sealer
- Calcium-enriched mixture (CEM).

AH PLUS

AH Plus consists of a paste–paste system, delivered in two tubes in a new double barrel syringe. The components of AH Plus are given in Table 1.2. The epoxide paste contains radiopaque fillers and aerosil. The amine paste consists of three different types of amines, radiopaque fillers, and aerosil.[25]

AH Plus has shown positive results when compared to other sealers [Figures 3-6].[25] It showed significantly lowest weight loss among the different root canal sealers in water and in artificial saliva with different pH values, independent of the solubility medium used. Furthermore, AH Plus showed the greatest stability in solution, as compared to the conventional sealers.[26]

AH Plus has a film thickness of 26 mm, which is clearly below the value of less than 50 mm required by the ISO standard for root canal sealing materials.[25] AH Plus has been designed to be slightly thixotropic. A flow of 36 mm also perfectly meets the requirements of the ISO standard (>25 mm).

It is known from the literature that pure epoxy resins develop mutagenic activities under the conditions of the Ames test. Therefore, the epoxide paste (paste A) and amine paste (paste B) were studied in the Ames test, in which the aqueous extracts did not induce any mutagenic effects. In numerous *in vivo* studies, the pure epoxy resins never showed any genotoxic effects.[27]

Recently, the antimicrobial effects of endodontic sealers (Endion, AH-26, AH-Plus, Procosol, and Ketac Endo) were investigated after 2, 20, and 40 days. AH Plus produced slight inhibition on *Streptococcus mutants* at 20 days and on *Actinomyces israelii* at every time interval. No effect was found on *Candida albicans* and *Staphylococcus aureus.*[28]

The studies showed that AH26 and Endomethasone sealers released formaldehyde after setting. Only a minimum release was observed for AH Plus (3.9 ppm), followed by EZ-Fill (540 ppm) endodontic cement and AH26 (1347 ppm) endodontic cement which yielded the greatest formaldehyde release.[29]

AH Plus has greater adhesion to root dentin than Epiphany as it is an epoxy resin–based sealer. AH Plus has better penetration into the micro-irregularities because of its creep capacity and long setting time, which increases the mechanical interlocking between sealer and root dentin and the cohesion of sealer causes Resilon to be more resistant to fracture.[30]

Kirsten *et al.*[31] investigated the mutagenicity of resin-based endodontic sealers by evaluating their potential to induce DNA double-strand breaks (DSBs) on extrusion into the periapical tissue and found that there were no indications for increased risk of genotoxicity of resin-based root canal sealers caused by the induction of DNA DSBs.

The strong link between sealer solubility and periapical re-infection indicates that water solubility of new sealers should be studied. So, Azadi *et al.*[32] studied the water solubility of five root canal sealers [AH26, Topseal, 2-Seal, Acroseal, and Roeko Seal Automix (RSA)] and found that the solubilitiesof the sealers AH26, Acroseal, Topseal, 2-Seal, and RSA were 0.28%, 0.36%, 0.07%, 0.037%, and 0.141%, respectively, after 24 h. After

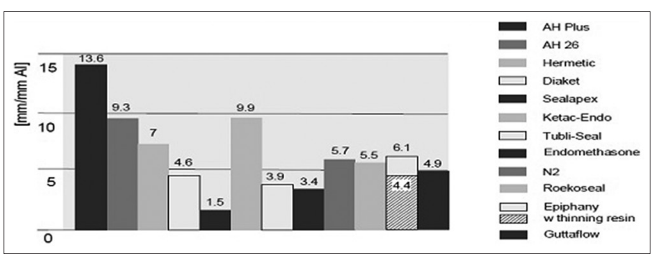

Figure 3: Radiopacity of root canal sealers

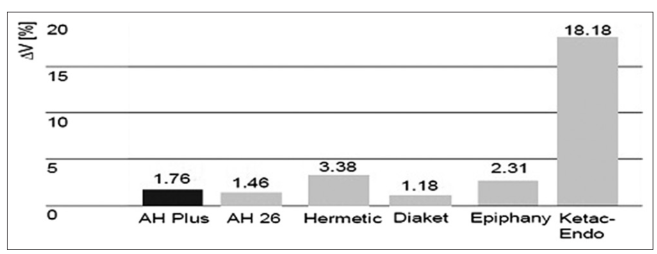

Figure 4: Polymerization shrinkage of root canal sealers

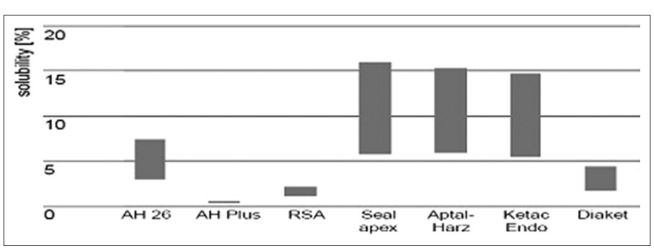

Figure 5: Solubility in different storage media over 28 days (Schafer 2003)

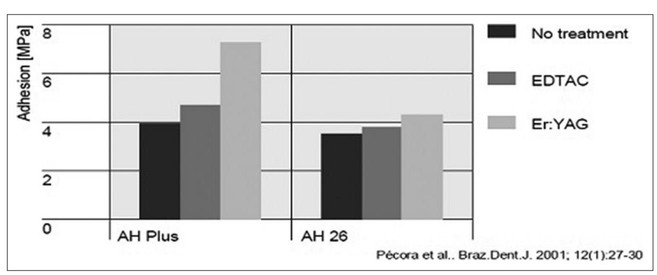

Figure 6: Adhesion to root canal dentine after various pre-treatment

28 days, their solubilities were 1.75%, 0.746%, 0.082%, 0.04%, and 0.517%, respectively, and the authors came to the conclusion that all the tested materials met the standards (maximum weight loss of 3% within 24 h). However, the results of 2-Seal followed by Topseal were the most favorable ones.

According to Franco *et al.*,[33] the oxygen inhibits vinyl polymerization in composite resins. Pecora *et al.*[34] found an adhesion of 4 MPa for AH Plus to dentin. After Er: YAG laser treatment of the root canal, the adhesion increased to about 7 MPa. Recently, Gogos demonstrated that a product identical to AH Plus exhibits a significant self-adhesion to dentin of 6.24 ± 1.43 MPa [Figure 7].[35]

Due to its excellent properties, such as low solubility, small expansion, adhesion to dentin, and very good sealing ability, AH Plus is considered as a benchmark "Gold Standard."[25]

GUTTAFLOW

In 1984, silicone was first introduced as a root canal sealer. A-silicones show comparatively little leakage, are virtually non-toxic, but display no antibacterial activity.

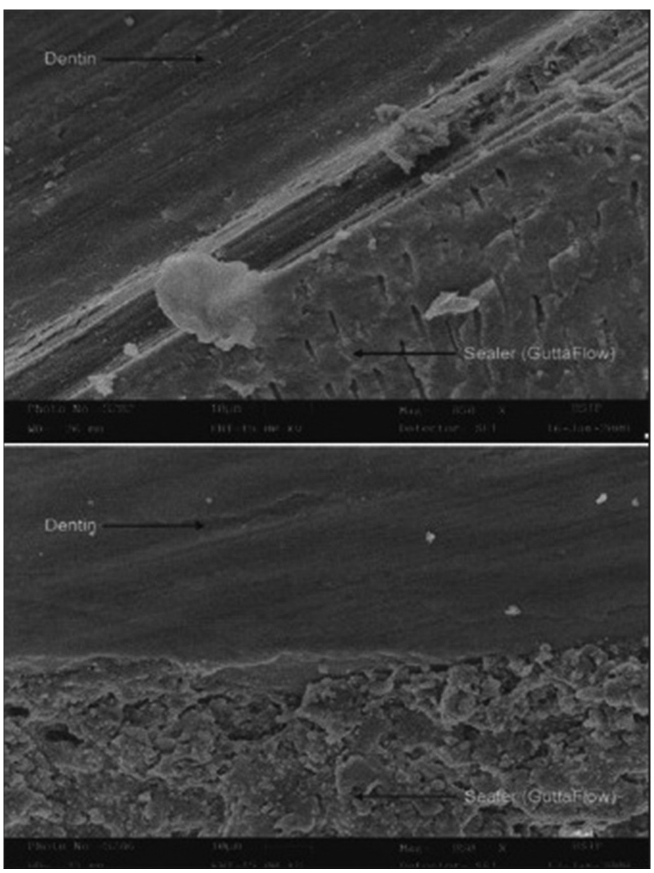

Figure 7: The homogeneity and adaption of a GuttaFlow to root canal walls and it was found that GuttaFlow completely filled the prepared root canal but small voids were frequently present within the core of the filling material (Upadhyay *et al.* 2011)

GP powder with a particle size of less than 30 nm has been introduced into a silicone matrix (polydimethylsiloxane (PDMS)). Silver particles have been added as preservative.[33,39] Working time is 15 min and setting time is 25-30 min. Components are given in Table 1.3 GuttaFlow is a cold, fluid obturation system that combines sealer and GP in a single material. It consists of a PDMS matrix which is highly filled with very finely ground GP. PDMS has only limited dimensional change in setting (about 0.6%-0.15%) and low water sorption. The finely ground GP powder and the silicone-based matrix are distributed homogeneously after mixing. GuttaFlow has very promising properties because of its insolubility, biocompatibility, post-setting expansion, great fluidity, and ability for providing a thin film of sealer,[40] and hence greater adhesion with the dentinal wall [Figure 7].[16]

GuttaFlow has nanosilver in its composition. Nanosilver is metallic silver which is distributed uniformly on the surface of the filling. It do not cause corrosion or color changes in the GuttaFlow. There is sufficient nanosilver in the material to prevent further spread of bacteria and is highly biocompatible.[41] GuttaFlow also showed poor wetting on the root dentin surface because of the presence of silicone, which possibly produces high surface tension forces, making the spreading of these materials more difficult.[42]

GuttaFlow showed good spreadability in the group where root dentin surface was treated with both ethylenediaminetetraacetic acid (EDTA) and sodium hypochlorite (NaOCl). The reason for this could be the increase in the surface energy of the root dentinal wall which was free of the smear layer.[42] A GP containing silicone sealer expands slightly, and thus leakage was reported to be less than for AH26 with GP over a period of 12 months.[43]

Dentin surface treated only with EDTA showed high contact angle value, suggesting the poor wettability of GuttaFlow. The high concentration of EDTA could have caused mild etching of the dentin surface leading to the exposure of collagen fibers, and the exposure of this hydrophobic moiety could have resulted in the increased contact angle.[44]

No data for systemic toxicity and allergy are available. However, based on the composition of the material, no adverse type reaction is to be expected.[39]

MTA-BASED SEALERS

This sealer produces calcium hydroxide,[47] which is released in solution[48] and induces formation of hydroxyapatite structures in simulated body fluid.[49] Newer developments of MTA include its use as a root canal sealer. Currently, three MTA sealer formulations are available: Endo CPM Sealer (EGEO SRL, Buenos Aires, Argentina), MTA Obtura (Angelus, Londrina PR, Brazil), and ProRoot Endo Sealer (Dentsply Maillefer, Ballaigues, Switzerland). Components are given in Table 1.4.

The composition of CPM sealer after mixing is reported to be 50% MTA (SiO_2, K_2O, Al_2O_3, SO_3, CaO, and Bi_2O_3), 7% SiO_2, 10% $CaCO_3$, 10% Bi_2O_3, 10% $BaSO_4$, 1% propylene glycol alginate, 1% propylene glycol, 1% sodium citrate, and 10% calcium chloride.[50]

MTA Obtura is a mixture of white MTA with a proprietary viscous liquid.[51] ProRoot Endo Sealer is calcium silicate–based endodontic sealer. The major components of the powder of ProRoot Endo Sealer are tricalcium silicate and dicalcium silicate, with inclusion of calcium sulfate as setting retardant, bismuth oxide as radiopacifier, and a small amount of tricalcium aluminate. Tricalcium aluminate is necessary for the initial hydration reaction of the cement. The liquid component consists of viscous aqueous solution of a water-soluble polymer and to improve The liquid component consists of viscous aqueous solution of a water soluble polymer to improve the workability.[52-55]

When placed in the canal, it releases calcium activity and causes cell attachment and proliferation, increases the pH, modulates cytokines like interleukin (IL) 4, IL6, IL8, IL10, and hence causes proliferation, migration, and differentiation of hard tissue producing hydroxyapatite which aids in the formation of physical bond between sealer and MTA.

The polymer did not seem to affect the biocompatibility of the materials and the hydration characteristics were similar to those reported for MTA.[56] Sealers based on MTA have been reported to be biocompatible, stimulate mineralization,[50] and encourage apatite-like crystalline deposits along the apical- and middle-thirds of canal walls.[52] These materials exhibited higher push-out strengths after storage in simulated body fluid[57] and had similar sealing properties to epoxy resin–based sealer when evaluated using the fluid filtration system.[50]

Fluoride-doped MTA demonstrated stable sealing up to 6 months, and was significantly better than conventional MTA sealers and comparable to AH Plus. The study supports the suitability of MTA sealers in association with warm GP for root filling.[58] Loise *et al.* evaluated the biocompatibility and bioactivity of a new MTA-based endodontic sealer, MTA Fillapex (MTA-F; Angelus, Londrina, Brazil), in human cell culture and came to the conclusion that after setting, the cytotoxicity of MTA-F decreases and the sealer presents suitable bioactivity to stimulate hydroxyapatite crystal nucleation.[60]

Sagsen *et al.* assessed the push-out bond strengths of two new calcium silicate–based endodontic sealers MTA Fillapex and iRoot SP and compared them with AH Plus in the root canals of extracted teeth and found that in the coronal specimens, there was no significant difference between the sealers. In the middle and apical segments, there was no significant difference between IRoot SP and AH Plus groups. However, the IRoot SP and AH Plus had significantly higher bond strength values than the MTA Fillapex. So, they concluded that MTA Fillapex had the lowest push-out bond values to root dentine compared with other sealers.[61]

Gomes-Filho *et al.* evaluated the rat subcutaneous tissue reaction to implanted polyethylene tubes filled with MTA Fillapex and compared it with MTA-Angelus, and concluded that MTA Fillapex was biocompatible and stimulated mineralization.[62]

Bortolini *et al.*[63] evaluated *in vitro* the intratubular penetration and permeability of Endo CPM Sealer in teeth contaminated with *Enterococcus faecalis* and concluded that Endo CPM sealer showed greater permeability to *E. faecalis* [Figure 8].

Morgental *et al.*[64] found that MTA Fillapex and Endo CPM Sealer has a good antibacterial effect on *E. feacalis* before setting, but not after setting despite having high pH.

Bin *et al.*[65] studied the cytotoxicity and genotoxicity of MTA canal sealer (Fillapex) compared with white MTA cement and AH Plus, and found that white MTA group was the less cytotoxic material in this study. Both AH Plus and Fillapex MTA sealer showed the lowest cell viability rates and caused an increased micronucleus formation.

Vidotto *et al.*[66] did the comparison of MTA Fillapex radiopacity with five root canal sealers (Endomethasone-N, AH Plus, Acroseal, Epiphany SE, and RoekoSeal) and concluded that in a decreasing order of radiopacity, AH Plus® (9.4 mm Al) was the most radiopaque sealer, followed by Epiphany SE (7.8 mm Al), MTA Fillapex (6.5 mm Al), RoekoSeal (5.8 mm Al), Endomethasone-N (4.5 mm Al), and Acroseal (3.5 mm Al). MTA Fillapex™ was the third most radiopaque sealer among all the tested sealers. Also, MTA Fillapex has the radiopacity degree in agreement with ADA specification No. 57.

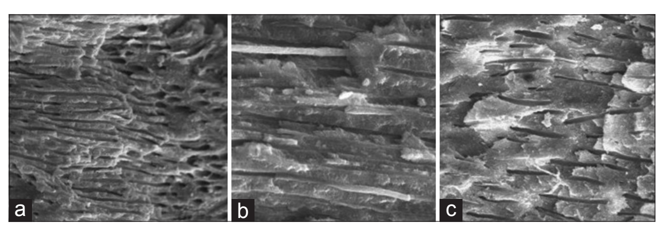

Figure 8: (a) Middle third with Endo CPM sealer: low intratubular penetration; (b) cervical third with EndoREZ: good intratubular penetration; and (c) apical third with AH Plus: regular intratubular penetration (1000 magnification) (courtesy: Bertolini *et al*. 2010)

Considering the elastic modulus of dentin which is about 14-18.6 GPa,[67] the reinforcing effect of MTA may be explained by its similar elastic modulus to dentin. This hypothesis also explains the gradual increase in the fracture resistance of MTA-filled teeth found by Hatibovic-Kofman *et al.*[68] Aalso, fracture resistance of MTA-filled teeth is time dependant.

The alkalinity of MTA can theoretically weaken root dentin similar to the findings on calcium hydroxide.[69-71] Another hypothesis is that a combination of little tensile strength of MTA and lack of bonding to dentin can weaken the dentin.[68] Regardless of the excellent biologic properties of MTA, the thin dentinal walls still make these teeth more prone to fracture and a reinforcing technique in these weak roots is necessary.

The novel sealer based on MTA has efficacious sealing ability. In contact with a simulated body fluid, the MTAs release calcium ions in solution and encourage the deposition of calcium phosphate crystals.

ENDOSEQUENCE BIOCERAMIC SEALER

EndoSequence BC Sealer (Brasseler, Savannah, GA, USA), also known as iRoot SP Injectable Root Canal Sealer (Innovative BioCeramix Inc., Vancouver, BC, Canada), is an example of a calcium phosphate silicate–based cement.[72] Its major inorganic components include tricalcium silicate, dicalcium silicate, calcium phosphates, colloidal silica, and calcium hydroxide. It uses zirconium oxide as the radiopacifier and contains water-free thickening vehicles to enable the sealer to be delivered in the form of a premixed paste.[73] Components are given in Table 1.5.

Hydroxyapatite is co-precipitated within the calcium silicate hydrate phase to produce a composite-like structure, reinforcing the set cement.[74] The introduction of a premixed calcium phosphate silicate–based sealer eliminates the potential of heterogeneous consistency during on-site mixing. Because the sealer is premixed with non-aqueous but water-miscible carriers, the water-free paste will not set during storage in the syringe and only hardens on exposure to an aqueous environment.[75]

EndoSequence BC Sealer uses the moisture within the dentinal tubules after canal irrigation to initiate and complete the setting reaction. Moreover, the presence of smear plugs and/or tubular sclerosis can affect the amount of moisture present.[76] The setting time of EndoSequence BC Sealer is 4 h and it may be extended in overly dry canals.[73] The pH of EndoSequence BC Sealer during the setting process is higher than 12 (Material Safety Data Sheet information), which increases its bactericidal properties.[77] The amount of Ca^{2+} released from EndoSequence BC Sealer was far higher (2.585 mg/l) than that released from AH Plus (0.797 mg/l), mainly after 7 days.[78]

Loushine *et al.*[79] investigated the setting time and micohardness of a premixed calcium phosphate silicate–based sealer in the presence of different moisture contents (0%-9 wt%). The moisture content that produced the most optimal setting properties was used to prepare set EndoSequence BC Sealer for cytotoxicity in comparison with AH Plus, and they concluded that cytotoxicity of AH Plus gradually decreased and became noncytotoxic, whereas BC Sealer remained moderately cytotoxic over the 6-week period. Hence, it shows bioceramic sealer is non-toxic and biocompatible.

Zoufan *et al.*[80] conducted a study which evaluated the cytotoxicity of GuttaFlow and EndoSequence BC sealers and compared them with AH Plus and Tubli-Seal sealers. The GuttaFlow and EndoSequence BC sealers had lower cytotoxicity than the AH Plus and Tubli-Seal sealers.

Hess *et al.*[83] evaluated the efficacy of solvent and rotary instrumentation in the removal of bioceramic sealer (BCS) when used in combination with GP as compared with AH Plus sealer and found that the working length (WL) was not regained in 70% of samples with BCS/master cone short of the WL. Patency was not re-established in 20% of samples with BCS/master cone to the WL or in 70% of samples with BCS/master cone short of the WL. Hence, it was concluded that conventional retreatment techniques are not able to fully remove BCS.

According to Ghoneim *et al.*,[84] bioceramic-based sealer (i.e., iRoot SP) is a promising sealer in terms of increasing *in vitro* resistance to the fracture of endodontically treated roots, particularly when accompanied with ActiV GP cones.

Deyan Kossev and Valeri Stefanov[85] found that when bioceramic-based sealers BioAggregate or iRoot SP are extruded, the pain is relatively small or totally absent. Such lack of pain may be explained based on the characteristics of these new materials. During hardening, they "produce" hydroxylapatite and after the end of hardening process they exhibit the same features as non-resorbable hydroxylapatite-based bioceramics used for bone replacement in oral surgery. Due to the hydroxylapatite formed, they are also osseo-conductive. During setting, hard ceramic-based sealers expand. Expansion of BioAggregate and iRoot SP and iRoot BP is significant (0.20%). These new bioceramic sealers also form chemical bond with the canal's dentin walls. That is why no space is left between the sealer and dentin walls [Figure 9].[85]

Borges *et al.*[86] compared the changes in the surface structure and elemental distribution, as well as the percentage of ion release, of four calcium silicate–

containing endodontic materials with a well-established epoxy resin–based sealer, submitted to a solubility test, and found that AH Plus and MTA-A were in accordance with ANSI/ADA's requirements regarding solubility, while iRoot SP, MTA Fillapex, and Sealapex did not fulfil ANSI/ADA's protocols. High levels of Ca^{2+} ion release were observed in all materials except AH Plus. Scanning electron microscopy (SEM)/Energy-dispersive X-ray spectroscopy (EDX) analysis revealed that all samples had morphological changes in both outer and inner surfaces after the solubility test. High levels of calcium and carbon were also observed at the surface of all materials except AH Plus and MTA-A.

Further studies should be conducted to evaluate the by-product components produced during setting to accurately assess the cytotoxicity of EndoSequence BC Sealer.

METHACRYLATE RESIN–BASED SEALER

Classification:
1. Hydron: First generation
2. EndoREZ: Second generation
3. RealSeal/Epiphany, Fibrefill: Third generation
4. RealSeal SE/MetaSEAL SE: Fourth generation

These are the bondable sealers, and therefore bond the core material along with the root canal wall, thus forming monoblock. Here we will be discussing about the formation of monoblock and where it pretermits along with other physical and compatibility properties. Components are given in Table 1.6.

Monoblock concept

Resilon is a synthetic polymer. The resin sealer attaches to it, as well as to the bonding agent/primer used to penetrate into the dentin tubules. As a result, a "monoblock" is formed, consisting of filling material resins sealer-bonding agent/primer-dentin. GP does not form a monoblock, even with the use of a resin-based sealer, because the sealer does not bind to GP. Moreover, the sealer tends to pull away from the GP on setting [Figures 10 and 11].[87]

The intent of a root canal monoblock is to achieve a total bond, and hence a total seal of the canal space has been hampered by the lack of chemical union between the polyisoprene component of GP and methacrylate-based resins. To evade this problem, coating GP cones with a polybutadiene di-isocyanate-methacrylate adhesive is done.[88] This is the first strategy. This adhesive resin includes a hydrophobic portion that chemically binds with hydrophobic polyisoprene substrate and a hydrophilic portion that is chemically compatible with a hydrophilic dentinal wall. With the use of this adhesive resin coating, a strong chemical union is achieved

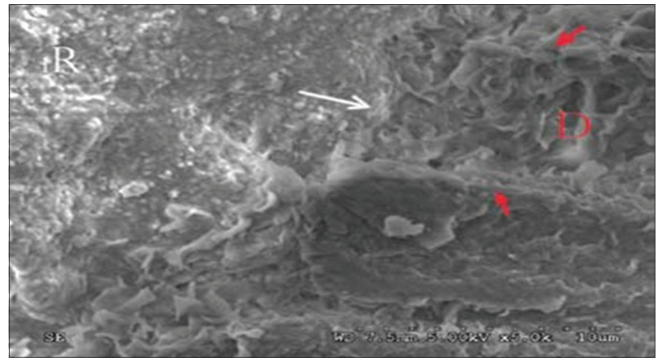

Figure 9: Bioceramic sealer iRoot SP. D-dentinal tubules of root canal wall. White arrow shows the interface between sealer and dentin without the presence of any voids because of chemical bond between dentin and sealer (courtesy: Deyan Kossev and Valeri Stefanov 2009)

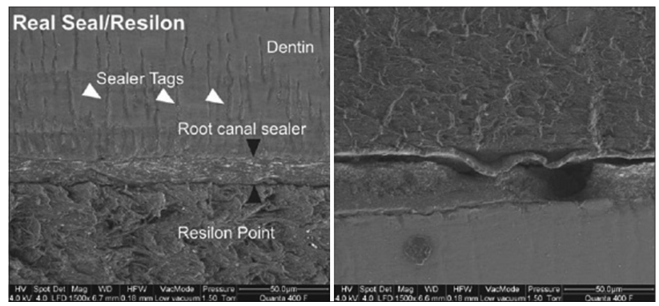

Figure 10: RealSeal/Resilon and gutta-percha/AH26 (courtesy Rosenberg *et al.* 2007)

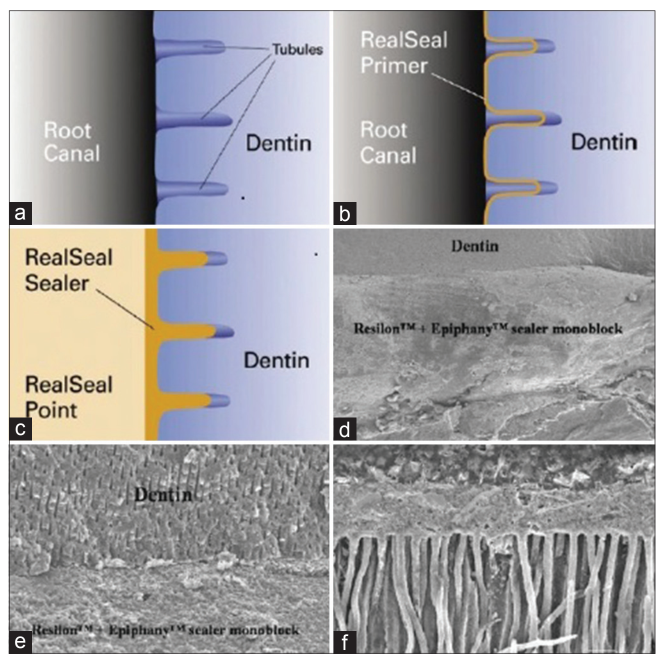

Figure 11: (a) Graphic illustration of dentinal tubules after smear layer removal. (b) Graphic illustration of Resilon primer penetration. (c) Graphic illustration of Resilon sealer penetration and Resilon point creating a monoblock of resin. (d) Resilon "monoblock" (×40). (e) Resilon "monoblock" (×650). (f) Sealer tags and Resilon (×1000) (Takagi S, Chow LC, Hirayama S, *et al.* 2003)

between the GP and the MRBS. This thermoplastic resin-coated GP cone is recommended for use with the EndoREZ system.[89] The second scheme uses a polycaprolactone and dimethacrylate-containing resin blend to form a filled thermoplastic composite (Resilon) that replaces GP as an alternative root filling material.[90]

The introduction of adhesive endodontics flings assurance, but also has some minuses.[91] For the second-generation EndoREZ system, gaps and silver leakage were identified between the GP resin coating and the EndoREZ sealer, even though a thin layer of hybridized dentin created by EDTA demineralization could be identified together with long resin tags.[92] When considering that the interface between the GP resin coating and the resin sealer is the only truly bondable interface in this system, this interface is a weak link that failed during polymerization shrinkage of the sealer. The chemical union between the polyisoprene component of the GP and the polybutadiene end of the resin coating molecule appears to be stronger than the coupling between the methacrylate end of the molecule and the resin sealer. Removal of the oxygen inhibition layer[93] from the surface of resin-coated GP cones during packaging has been hypothesized for their weak adhesion to the methacrylate resin–based root canal sealer, resulting in their frequent delamination from the sealer after root canal obturation. Hiraishi *et al.*[94] attempted to improve the shear strength of the resin-coated GP to the EndoREZ sealer by generating active free radicals for chemical coupling via *in situ* application of a dual-cured dentin adhesive to the resin-coated GP. They observed a fivefold increase in shear strength after adhesive application, with complex interfacial failures instead of complete sealer delamination from the resin coating.

The adhesive strength of Resilon to a third-generation MRBS was 4-5 times lower than the bond strength of a composite resin to the same sealer,[95] suggesting that the coupling of MRBSs to Resilon is very weak. This occurrence might be attributed to the phase separation of the emulsified dimethacrylate phase within a continuous polycaprolactone phase.[96] The bond strength of Epiphany to Resilon was reported to be lower than the bond strength of AH26, an epoxy resin–based sealer to Resilon.[100]

The fourth-generation self-adhesive type root canal sealers are still relatively new, and detailed information on their adhesive properties to root filling materials is limited or lacking. For the 4-META containing sealer MetaSEAL, a recent report identified a hybrid layer-like structure along the GP–sealer interface.[97] However, no data are currently available on the adhesive strength of MetaSEAL to GP via this hybrid layer-like interface. Taken together, these data suggest that the chemical coupling between contemporary MRBSs to root filling materials is generally weak or insufficiently optimized. In view of the extremely high C-factor encountered in long, narrow root canals,[98] it is doubtful whether the core material–sealer bond is capable of resisting polymerization shrinkage stresses that develop during the setting of the resin sealer to permit the realization of the goal of creating a monoblock in the root canal system.

The existence of monoblock throughout the entire root canal system was not seen in a study by Tay *et al.*[99] SEM evaluated the ultrastructural quality of the apical seal of canals obturated using the Resilon system compared to canals obturated with GP and a resin sealer. Excellent coupling was found between the Resilon and sealer; both gap-free and gap-containing segments were viewed along the dentin–sealer interface. Similar gap-free and gap-containing segments were observed in the GP group. Gap formation was likely created due to the polymerization contraction of the methacrylate-based resin sealer.[99,100]

Studies on different physical properties of methacrylate-based sealers

While the low interfacial bond strengths found in the research of Tay *et al.* and Gesi *et al.* cast doubts on the ability of Resilon to strength roots, the initial study by Teixeira *et al.* found that Resilon obturated teeth were more than 20% stronger than the teeth obturated with GP and resin sealer.[100]

The retention mechanisms suggested by the manufacturers of methacrylate resin–based root canal sealers (i.e., dentin hybridization and profuse resin tag formation) are likely to be contributed by the combined dentin demineralization effects of EDTA[101] and the sealer system.

When EDTA was used as the final rinse, the smear layer was completely dissolved and a thin layer of partially demineralized dentin could be identified on the intact dentin surface, irrespective of whether the sealer was non-etching (EndoREZ) or self-etching (RealSeal, Meta-SEAL, and RealSeal SE).[102]

For methacrylate resin-based sealers, thin films had higher bond strength than thick films ($P<0.001$ for both tensile and shear bond strength). With the epoxy-based sealer, either no difference (shear) or lower bond strength in thin films (tensile; $P<0.05$) was found, and appeared to result from numerous voids created during mixing.[103]

It is normally seen that polymerization shrinkage occurs more when resin sealer is sparsely filled, and used in low viscosity which creates the gap in sealer–dentin interface and can allow the microorganism to penetrate and multiply. So, slow polymerization of the dual-curable sealers would improve the chance for the relief of shrinkage stress via resin flow. The slow self-curing mechanism of some of these sealers is supposed to promote stress relief via prolonged gelation time during the initial setting stage.[104]

Epiphany (RealSeal)-filled canals also contained significantly more voids and gaps than those filled with GP and conventional sealers.[105]

Pulling of resin sealer tags out of the tubules during polymerization shrinkage of the sealer might create gaps along the sealer–dentin interface.[110] Heat generation during warm vertical compaction and searing of the sealer from the canal orifices with a heat source could have expedited the setting of the sealers, defeating the purpose of incorporating delayed polymerization mechanisms and preventing relief of polymerization stresses by slow flow.[111,112]

While excellent coupling was found between the Resilon and sealer, both gap-free and gap-containing segments were viewed along the dentin-sealer interface. Similar gap-free and gap-containing segments were observed in the gutta-percha group. Further apical leakage was observed in all gutta-percha obturated canals and 9 of 10 Resilon obturated canals. The authors speculated that gap formation was likely created due to the polymerization contraction of the methacrylate-based resin sealer.[113]

It is known that polymers degrade over time through physical and chemical processes.[114] As the bond degrades, interfacial leakage increases, which resembles *in vivo* aging. In addition, Resilon is susceptible to alkaline[115] and enzymatic[116] hydrolysis. Therefore, biodegradation of Resilon by bacterial/salivary enzymes and endodontically relevant bacteria might occur in the event of apical or coronal leakage. Many studies have been performed and it is seen that leakage results vary too much [Figure 12].

The chemical coupling between contemporary MRBSs and root filling materials is generally weak or insufficiently optimized. In view of the extremely high C-factor encountered in long, narrow root canals,[117] it is doubtful whether the core material–sealer bond is capable of resisting polymerization shrinkage stresses that develop during the setting of the resin sealer to permit the realization of the goal of creating a monoblock in the root canal system.

Teixeira *et al.*[118] showed that roots filled with Resilon/Epiphany exhibited significantly higher fracture load values than those filled with GP/AH26 when the specimens were subjected to vertical loading forces. This finding was supported by other studies demonstrating that roots filled with MRBSs exhibited higher resistance to fracture than those filled with GP and sealers[119] [Figure 13].

Hammad *et al.*[120] reported that Epiphany and EndoREZ groups showed significantly higher fracture loads than GP and GuttaFlow (Coltene/Whaledent Inc., Cuyahoga Falls, OH, USA) groups. However, opposing results were reported by other studies showing that bondable root filling materials did not improve the overall mechanical properties of the root dentin. In those studies, the combined use of Epiphany (RealSeal)/Resilon was unable to reinforce endodontically treated teeth against horizontal fracture forces[121-123] as well as vertical loading forces.[122-124]

It is perceived that MRBSs are not able to influence the mechanical properties of root canal dentin might be due to the following factors: (1) polymerization along the sealer–dentin interface in the coronal part of the root is possibly affected by oxygen inhibition;[125] (2) creeping of incompletely polymerized resinous sealers, which results in failure along the sealer–dentin interface;[126] (3) presence of residual monomers in the root canals;[127] and most importantly, (4) the low cohesive, tensile, compressive strengths and modulus of elasticity of the currently available root filling materials when compared with dentin, with the former behaving as elastomers that dissipate instead of transmitting stresses.[124]

Toxicity of Epiphany might be explained by the presence of unpolymerized hydrophilic monomers (such as 2-hydroxyethyl methacrylate (HEMA)) that can easily diffuse into the cell and elicit significant toxicity. Epiphany

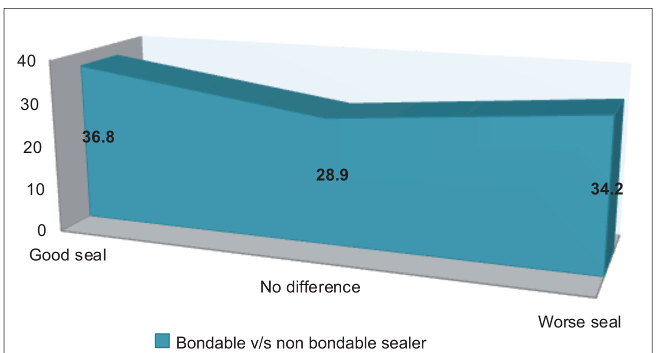

Figure 12: The extent of leakage between teeth that were filled with methacrylate resin–based sealers versus conventional nonbonding sealers (courtesy: Kim *et al.* 2009)

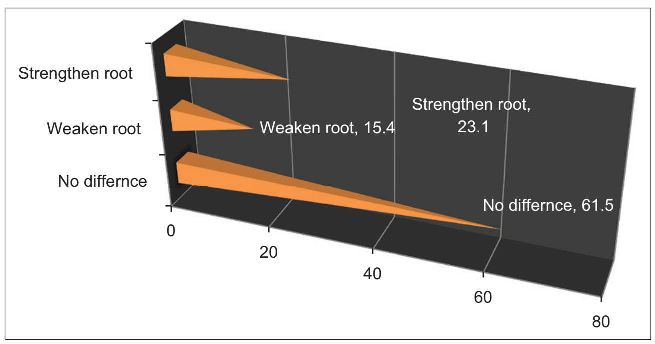

Figure 13: Results of *in vitro* studies to examine whether the use of methacrylate resin–based sealers and bondable root filling materials is able to improve the fracture resistance of root-filled teeth (courtesy: Kim *et al.* 2009)

requires body temperature and total elimination of air contact to polymerize. It polymerized within 30 min in an anaerobic environment, but in the presence of air, material setting took up to 7 days.[128]

There is a general consensus that MRBSs used with Resilon or GP were more effectively removed, with fewer remnant filling materials than conventional sealer/FP combinations. Easier removal and less remnant materials would imply that MRBSs do not bond well to sclerotic dentin that is present in the apical part of the canal walls. Epiphany is insoluble in the solvents commonly used in dentistry. Thus, removal of resin sealers from fins, accessory canals, or canal isthmi remains a challenge. Ezzie *et al.*[129] found that Resilon left less residual debris in the apical third of the root canal; this may be due to the fact that effective removal of the smear layer and subsequent bonding is difficult to achieve in this area.

Al-hiyasat (2010) investigated the cytotoxic effects of four resin-based root canal sealers, namely, AH Plus, an epoxy resin; EndoREZ, a single-methacrylate–based sealer; Epiphany, a multi-methacrylate resin–based sealer; and MetaSEAL, one of the latest generation methacrylate 4-META–containing resin-based sealers, and found that MetaSEAL was most cytotoxic and AH Plus was least cytotoxic.[108]

Javaheri *et al.*[149] conducted a study to evaluate the fracture resistance of teeth restored with two obturation and two filling systems. They found that composite resin restorations may recover significantly more fracture resistance than those bonded with amalgam. Resilon–Epiphany may have slightly, but not significantly superior results in terms of fracture resistance, as shown in Figure 14.

CALCIUM PHOSPHATE SEALER

Bae *et al.*[135] investigated the cellular effects of newly developed calcium phosphate–based sealers (CAPSEAL I and II) using cultured human periodontal ligament cells (HPDLCs), in comparison with epoxy resin sealer (AH26; Dentsply, DeTrey, Konstanz, Germany), ZOE sealer (EWT; Kerr Corporation, Orange, CA, USA), and CPC sealer (Sankin apatite sealer; Sankin-kogyo, Tokyo, Japan), and found that both CAPSEAL I and II show less cytotoxicity and inflammatory mediators compared with the other sealers and have the potential to promote bone regeneration as root canal sealers. Components are given in Table 1.7.

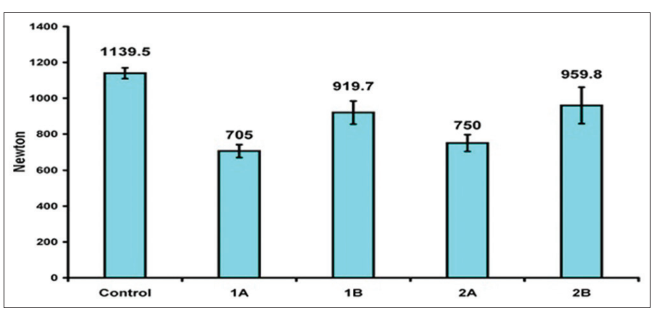

Figure 14: Mean fracture loads and standard deviations (N) of the studied groups. Control = no obturation; 1A = AH26–gutta-percha + bonded amalgam; 1B = AH26–gutta percha + composite restoration; 2A = epiphany–resilon + amalgam bond; 2B = epiphany–resilon + composite restoration. Control = intact tooth (courtesy: Javaheri *et al.* 2012) 148

Shon *et al.*[136] examined the biological effects of new calcium phosphate–based root canal sealers, CAPSEAL I and CAPSEAL II (CPS), on human periodontal fibroblast cells by examining the expression levels of inflammatory mediators and compared the effects of CPS on the viability and osteogenic potential of human osteoblast MG63 cells, with those of other commercially available calcium phosphate sealers [Apatite Root Sealer type I (ARS I)] and [Apatite Root Sealer III (ARS III); Sankin Kogyo, Tokyo, Japan] and an ZOE-based sealer [Pulp Canal Sealer EWT (PCS EWT); Kerr, Detroit, MI, USA) and came to the conclusion that CAPSEAL I and II facilitate the periapical dentoalveolar and alveolar healing by controlling cellular mediators from PDL cells and osteoblast differentiation of precursor cells.

Khashaba *et al.*[138] evaluated the histopathologic biocompatibility of two new calcium phosphate–based sealers (CPS-1 and CPS-2) with a commercially available calcium hydroxide–based sealer (Acroseal) and found that CPS-1 sealer was not biocompatible. CPS-2 sealer and Acroseal had a favorable biocompatibility level based on the histological findings.

Accordingly, Yang *et al.*[139] did field emission-scanning electron microscopy and found that both CAPSEAL I and II sealers were well adapted to the canal wall and infiltrated into the dentinal tubules.

CALCIUM-ENRICHED MIXTURE

White *et al.* showed weakening of dentinal structure in short term and attributed this effect to the structural alteration of proteins caused by the alkalinity of MTA.[140] Recently, a new biomaterial, CEM cement has been introduced.[141] This cement consists mainly of CaO, SO3, P2O5, and SiO2. CEM cement releases calcium hydroxide during and after setting.[141,142] This cement has antibacterial features similar to calcium hydroxide and better than MTA.[142,143] On comparison with MTA, this novel cement was found to have similar sealing ability and pH and increased flow, but decreased working time and film thickness.[144] It has shown its capacity in regenerating PDL and induction of cementogenesis.[145]

Milani *et al.*[146] evaluated the strengthening effect of MTA and CEM and found it to be the same for MTA and CEM. Andreasen *et al.*[147] have advocated placing calcium hydroxide for a maximum of 4 weeks followed by filling the canal with MTA. This abbreviates the duration of the high fracture risk phase of calcium hydroxide dressing and allows much earlier placement of strength enhancing restorative materials. In contrast to the aforementioned studies, other investigators believe that the alkalinity of MTA can theoretically weaken root dentin, similar to the findings on calcium hydroxide.[148] Lack of data on modulus elasticity of CEM, the mechanism of reinforcing effect of CEM remains to be elucidated. Lack of data on modulus elasticity of CEM, the mechanism of reinforcing effect of CEM when used as a sealer remains to be elucidated.

An important issue neglected in the studies on fracture strength of MTA-filled teeth is the role of fatigue. None of these studies applied cyclic loads prior to fracture testing. However, it is recommended to consider this issue in future studies on fracture strength of immature teeth.

CONCLUSION

The evolution of sealers is from the conventional ZOE to the contemporary ones like epoxy-based resin and MRBS, and to the most recent MTA sealer and bioceramic sealer, which have the predilection to change the perception the way sealers have been used in the near future. MTA and bioceramic sealer have opened a new dimension on how apart from creating hermetic seal, a sealer can also have the propensity toward mineralization through the formation of hydroxyapatite crystals.

It is seen that in contact with a simulated body fluid, the MTA sealer and bioceramic sealer released calcium in solution and encouraged the deposition of calcium phosphate crystals, and have superior sealing ability as compared to resin-based sealer though more study needs to be done as far as retreatment and fracture resistance is concerned.

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