A review of bioceramic technology in endodontics

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_Since bioceramic technology was introduced to endodontics, the response has been exceptional. As more and more practitioners have thought through the process, they have been able to see not only the clear benefits of this technology in endodontics, but they are now asking how this technology can be applied to other aspects of dentistry. The application of bioceramic technology has not only changed endodontics both surgically and non surgically, it has also begun to change the way we treatment plan our patients. As a result of bioceramic technology, we now have the ability to save more teeth in a predictable fashion, while, in addition, improving their long-term prognosis. The option of "saving the natural dentition" is now back on the table.

However, before we investigate specific techniques, we must first ask ourselves, "What are bioceramics?" Bioceramics are ceramic materials specifically designed for use in medicine and dentistry. They include alumina and zirconia, bioactive glass, glass ceramics, coatings and composites, hydroxyapatite and resorbable calcium phosphates.[1,2]

There are numerous bioceramics currently in use in both dentistry and medicine, although more so in medicine. Alumina and zirconia are among the bioinert ceramics used for prosthetic devices. Bioactive glasses and glass ceramics are available for use in dentistry under various trade names. Additionally, porous ceramics such as calcium phosphate-based materials have been used for filling bone defects. Even some basic calcium silicates such as ProRoot MTA (Dentsply) have been used in dentistry as root repair materials and for apical retrofills.

It is important to understand the specific advantages of bioceramics in dentistry and why they have become so popular. Clearly the first reason is related to physical properties. Bioceramics are exceedingly biocompatible, non-toxic, do not shrink, and are chemically stable within the biological environment. Additionally, and this is very important in endodontics, bioceramics will not result in a significant inflammatory response if an over fill occurs during the obturation process or in a root repair.

A further advantage of the material itself is its ability (during the setting process) to form hydroxyapatite and ultimately create a bond between dentin and the filling material. A significant component of improving this adaptation to the canal wall is the hydrophilic nature of the material. In essence, it is a bonded restoration. However, to fully appreciate the properties associated with the use of bioceramic technology, we must understand the hydration reactions involved in the setting of the material.

_EndoSequence BC sealer setting reactions

The calcium silicates in the powder hydrate to produce a calcium silicate hydrate gel and calcium hydroxide. The calcium hydroxide reacts with the phosphate ions to precipitate hydroxyapatite and water. The water continues to react with the calcium silicates to precipitate additional gel-like calcium silicate hydrate. The water supplied through this reaction is an important factor in controlling the hydration rate and the setting time in the following equations.

The hydration reactions (A, B) of calcium silicates can be approximated as foloows:

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

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

The precipitation reaction (C) of calcium phosphate apatite is as follows:

$$7Ca(OH)_2 + 3Ca(H_2PO_4)_2 \rightarrow Ca_{10}(PO_4)_6(OH)_2 + 12H_2O \quad \text{(C)}$$

For clinical purposes (in endodontics), the advantages of a premixed sealer should be obvious. In addition to a significant saving of time and convenience, one of the major issues associated with the mixing of any cement, or sealer, is an insufficient and non-homogenous mix. Such a mix may ultimately compromise the benefits associated with the material. Keeping this in mind, a new premixed bioceramic sealer has been designed that hardens only when exposed to a moist environment, such as that produced by the dentinal tubules.[3]

But, what is it specifically about bioceramics that make them so well suited to act as an endodontic sealer? From our perspective as endodontists, some of the advantages are: high pH (12.8) during the initial 24 hours of the setting process (which is strongly anti-bacterial); they are hydrophilic, not hydrophobic; they have enhanced biocompatibility; they do not shrink or resorb (which is critical for a sealer-based technique); they have excellent sealing ability; they set quickly (three to four hours); and they are easy to use (particle size is so small it can be used in a syringe).

The introduction of a bioceramic sealer (EndoSequence BC Sealer, Brasseler USA) allows us, for the first time, to take advantage of all the benefits associated with bioceramics but to not limit its use to merely root repairs and apical retrofills. This is possible only because of recent nanotechnology developments; the particle size of BC Sealer is so fine (less than two microns), it can actually be delivered with a 0.012 capillary tip (Fig. 1).

This material has been specifically designed as a non-toxic calcium silicate cement that is easy to use as an endodontic sealer. This is a key point. In addition to its excellent physical properties, the purpose of BC Sealer is to improve the convenience and delivery method of an excellent root canal sealer, while simultaneously taking advantage of its bioactive characteristics (it utilizes the water inherent in the dentinal tubules to drive the hydration reaction of the material, thereby shortening the setting time).

As we know, dentin is composed of approximately 20 percent (by volume) water, and it is this water that initiates the setting of the material and ultimately results in the formation of hydroxyapatite.[4] Therefore, if any residual moisture remains in the canal after drying, it will not adversely affect the seal established by the bioceramic cement. This is very important in obturation and is a major improvement over previous sealers. Furthermore, its hydrophilicity, small particle size and chemical bonding to the canal walls also contribute to its excellent hydraulics. But there is another aspect to sealer hydraulics. That is the shape of the prepared canal itself.

Actually, it all begins with the file. To be more specific, it all begins with the specific preparation created by the file — a constant taper preparation. When using the EndoSequence technique, we can create either a 0.04 constant taper preparation or a 0.06 taper. The real key is the constant taper preparation, because when accomplished it now gives us the ability to create predictable, reproducible shapes. A variable taper preparation is not recommended because its lack of shaping predictability (and its corresponding lack of reproducibility) will lead to a less than ideal master cone fit. This lack of endodontic synchronicity is why all variable taper preparations are associated with the overly expensive and more time consuming thermoplastic techniques.

Fig. 1

Fig. 1_The particle size of BC Sealer is so fine (less than two microns), it can actually be delivered with a 0.012 capillary tip. (Photos/Provided by Real World Endo)

Knowing in advance what the final shape (constant taper preparation) will be is a tremendous advantage in creating superior hydraulics. Then add in the feature of laser-verified paper points and gutta-percha cones, and we now start to develop a system where everything matches (true endodontic synchronicity).

This concept of having everything match is so important because it allows us, for the first time, to perform rotary endodontics in a truly conservative fashion and to be able to use a hydraulic condensation technique.

Furthermore, when used in conjunction with the EndoSequence filing system, this becomes a synchronized hydraulic condensation technique. This has tremendous implications for the tooth as evidenced by a recent study published in the Journal of Endodontics.[5] The purpose of this study was to evaluate and compare the fracture resistance of roots obturated with various contemporary filling systems. The investigators (Ghoneim, et al.) instrumented 40 single-canal premolars using 0.06 taper EndoSequence files. The teeth were then obturated using four different techniques. Group I used a bioceramic sealer iRoot SP (IRoot SP is BC Sealer in Europe) in combination with ActiV GP cones (Brasseler USA) while Group II used the bioceramic sealer with regular gutta-percha. Group III utilized ActiV GP sealer plus ActiV GP cones and Group IV employed ActiV G sealer with conventional gutta-percha cones. All four groups were obturated using a single cone technique. Ten teeth were left unprepared and these acted as a negative control for the study.

Following preparation and obturation, all the teeth were embedded in acrylic molds and then subjected to a fracture resistance test in which a compressive load (0.5 mm/min) was applied until fracture. Subsequently, all data was statistically analyzed using the analysis of variance model and the Turkey post hoc test.

The results generated were quite remarkable. It was demonstrated that the significantly highest fracture

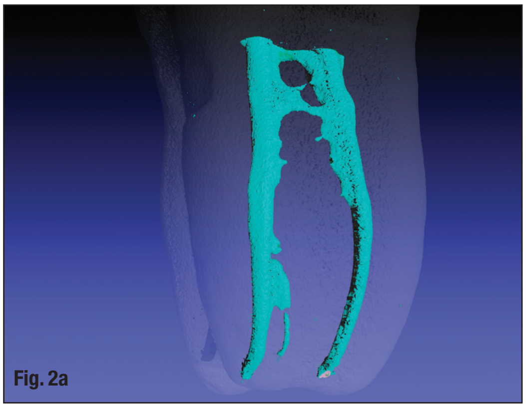


Fig. 2a

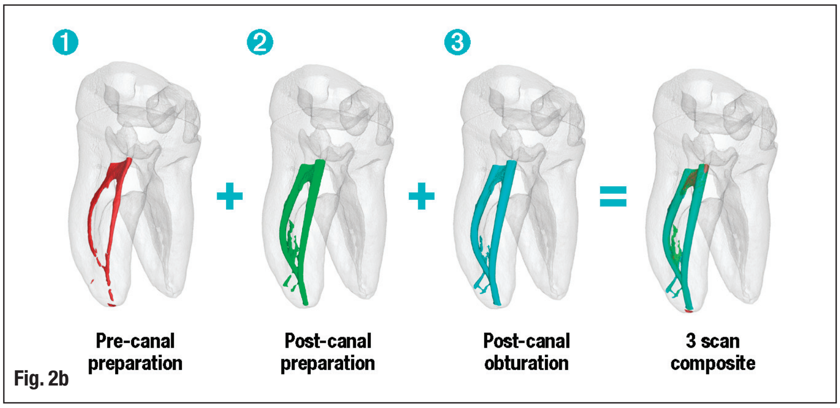


Fig. 2b

Fig. 2a_This image shows the excellent adaption of the bioceramic sealer (and gutta-percha) to the true shape of the prepared canal.

Fig. 2b_A composite image demonstrating the true excellence of the technique.

resistance was recorded for both the negative control and Group I (bioceramic sealer /Activ GP cone) with no statistical difference between them. The lowest reported value was in Group IV, which employed ActiV GP sealer in combination with regular gutta-percha cones.

The conclusion of this study was that employing a bioceramic sealer (such as BC Sealer) is very promising in terms of strengthening the residual root and increasing the in vitro fracture resistance of endodontically treated teeth. This is a very significant finding, especially regarding the long-term retention of an endodontically treated tooth.

In this particular study, the bioceramic sealer performed best when combined with ActiV GP cones. In fact, bonding will occur between the bioceramic sealer and the ceramic particles in the ActiV GP cones as well as to the bioceramic particles present in the new bioceramic coated cones (BC cones). The technique of achieving a true bond between the root canal wall and the master cone (as a result of creating endodontic synchronicity and advanced material science) is known as synchronized hydraulic condensation.

_Synchronized hydraulic condensation

The technique with this material is quite straightforward. Simply remove the syringe cap from the EndoSequence BC Sealer syringe. Then attach an Intra Canal Tip of your choice to the hub of the syringe. The Intra Canal Tip is flexible and can be bent to facilitate access to the root canal. Also, because the particle size has been milled to such a fine size (less than 2 microns), a capillary tip (such as a 0.012) can be used to place the sealer.

Following this procedure, insert the tip of the syringe into the canal no deeper than the coronal one third. Slowly and smoothly dispense a small amount of EndoSequence BC Sealer into the root canal. Then remove the disposable tip from the syringe and proceed to coat the master gutta-percha cone with a thin layer of sealer. After the cone has been lightly coated, slowly insert it into the canal all the way to the final working length. The synchronized master gutta-percha cone will carry sufficient material to seal the apex.[6]

The precise fit of the EndoSequence gutta-percha master cone (in combination with a constant taper preparation) creates excellent hydraulics and, for that reason, it is recommended that the practitioner use only a small amount of sealer. Furthermore, as with all obturation techniques, it is important to insert the master cone slowly to its final working length. Moreover, the EndoSequence System is now available with bioceramic coated gutta-percha cones. So in essence, what we can now achieve with this technique is a chemical bond to the canal wall, as a result of the hydroxyapatite that is created during the setting reaction of the bioceramic material and we also have a chemical bond between the ceramic particles in the sealer and the ceramic particles on the bioceramic coated cone.

Think about what we have just accomplished. We are now doing root canals in a manner that truly is easier, faster and better. As further evidence of this technique, we asked Dr. Adam Lloyd, the chairman of the Department of Endodontics at the University of Tennessee, to share the results of a study recently conducted at the University of Tennessee.[7]

_Materials and methods

Sixteen recently extracted human molars were mounted on individual stubs and underwent an initial high spatial resolution CT scan prior to any treatment. Following biomechanical crown-down canal preparation to an apical matrix of 35/0.04 and ultrasonic irrigation with 6 percent sodium hypochlorite, each sample was scanned a second time. Obturation was completed using a single matched gutta-percha cone and EndoSequence BC sealer. The coronal 4 mm of the gutta-percha was thermo-softened and compacted vertically. Subsequent to canal obturation, a third scan was made.

Scanning of the specimens was performed (Actis 150/130, Varian Medical Systems, Palo Alto, Calif.) with a 180-degree rotation around the vertical axis and a single rotation step of 0.9 degree with a cross-sectional pixel size of approximately 24 µm. All three backscatter pro-

Figs. 3a–5c_Cases treated with bioceramics. (Clinical X-rays/Provided by Allen Ali Nasseh, DDS, MMSc)

jections were aligned post-processing with sub-voxel accuracy at 92 percent CI in VG Studio Max 2.1 (Volume Graphics GmbH, Heidelberg, Germany) and manipulated to create regions of interest for each of the scans.

_Results

Analysis of volume occupied by sealer in relation to total original canal volumes was found to be extremely high with a mean of 97 percent ± 2.8, much higher than reported previously using studies on canal surface area occupancy of material, with 75 percent of samples occupied at the ≥ 95 percent level (Figs. 2a, 2b).

While the properties associated with bioceramics make them very attractive to dentistry, in general, what would be their specific advantage if used as an endodontic sealer? From our perspective as endodontists, some of the advantages are: enhanced biocompatibility; possible increased strength of the root following obturation; high pH (12.8) during the setting process, which is strongly anti-bacterial; sealing ability related to its hydophilicity; and ease of use.[8] Furthermore, the bioceramic sealer does not shrink upon setting (it actually expands 0.002 percent) and once it is fully set, the material will not resorb.

The cases pictured in Figures 3a through 5c demonstrate the excellence of this technique.

_Retreatment of bioceramics

Bioceramic sealer cases are definitely retreatable yet the issue of retreating these cases (and all the associated misinformation) is not unlike that of glass ionomer. Historically there has been confusion about retreating glass ionomer endodontic cases (glass ionomer sealer is definitely retreatable when used as a sealer) and, similarly, there has been confusion concerning the retreatability of bioceramics.[8] The key is using bioceramics as a sealer, not as a complete filler. This is why endodontic synchronicity is so important and again, why the use of constant tapers makes so much sense (it minimizes the amount of endodontic sealer thereby facilitating retreatment).

The technique itself is relatively straightforward. The key in retreating bioceramic cases is to use an ultrasonic with a copious amount of water. This is particularly important at the start of the procedure in the coronal third

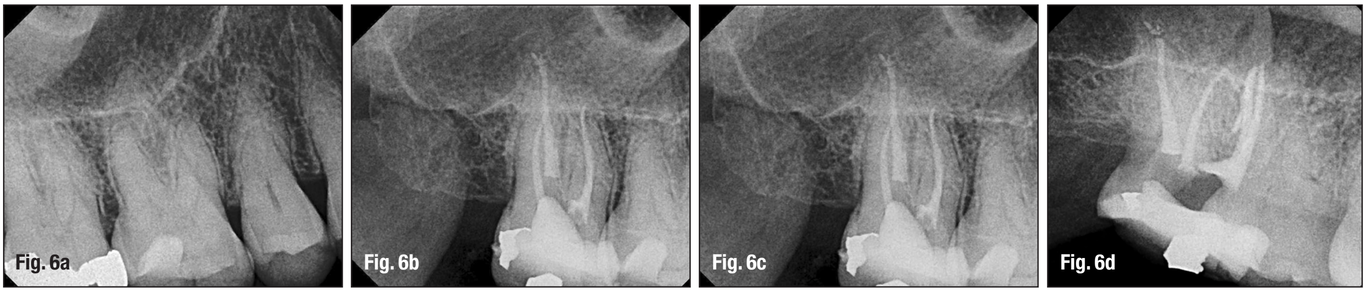


Fig. 6a Fig. 6b Fig. 6c Fig. 6d

Figs. 6a–6d_A case demonstrating retreatment of BC Sealer. (Clinical X-rays/Provided by Allen Ali Nasseh, DDS MMSc)

Fig. 7

Fig. 7_EndoSequence Root Repair Material. (Photos/Provided by Real World Endo)

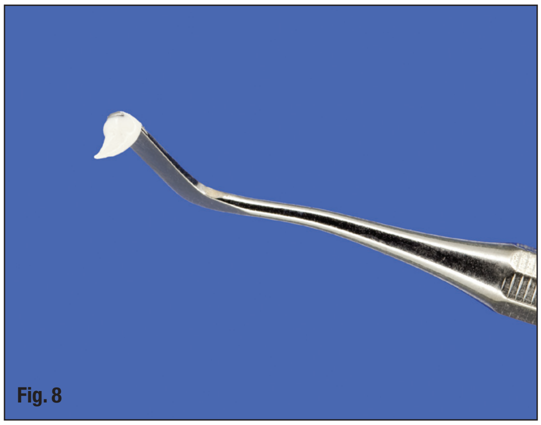


Fig. 8

Fig. 8_A section of material ready for delievery.

of the tooth. Work the ultrasonic (with lots of water) down the canal to approximately half its length. At this point, add a solvent to the canal (chloroform or xylol) and switch over to an EndoSequence file (#30 or 35/0.04 taper) run at an increased rate of speed (1,000 RPM). Proceed with this file, all the way to the working length, using solvent when indicated. An alternative is to use hand files for the final 2-3 mm and then follow the gutta-percha removal with a rotary file to ensure synchronicity.

The case pictured in Figures 6a through 6d demonstrates the retreatment of BC Sealer.

_Bioceramics as a root repair material

We are all familiar with the success of MTA (mineral trioxide aggregate) as a root repair and apico retrofilling material. Furthermore, we realize that because MTA is a modified Portland cement, it has some limitations in terms of handling characteristics. It does not come premixed (and therefore must be mixed by hand), is difficult to use on retrofills, and has such a large particle size that it cannot be extruded through a small syringe. Yet it has a number of favorable characteristics, including a pH of 12.5, which is significantly anti-bacterial. However, in lieu of a Portand cement-based material, we now have available a medical grade bioceramic repair material.

This new repair material is, in fact, the EndoSequence Root Repair material, which comes either premixed in a syringe (just like BC Sealer) or as a premixed putty (Fig. 7). This is a tremendous help not just in terms of assuring a proper mix but also in terms of ease of use. We now have a root repair material with an easy and efficient delivery system. This is a key development and a serious upgrade. This allows many clinicians, not just specialists, to take advantage of its properties.

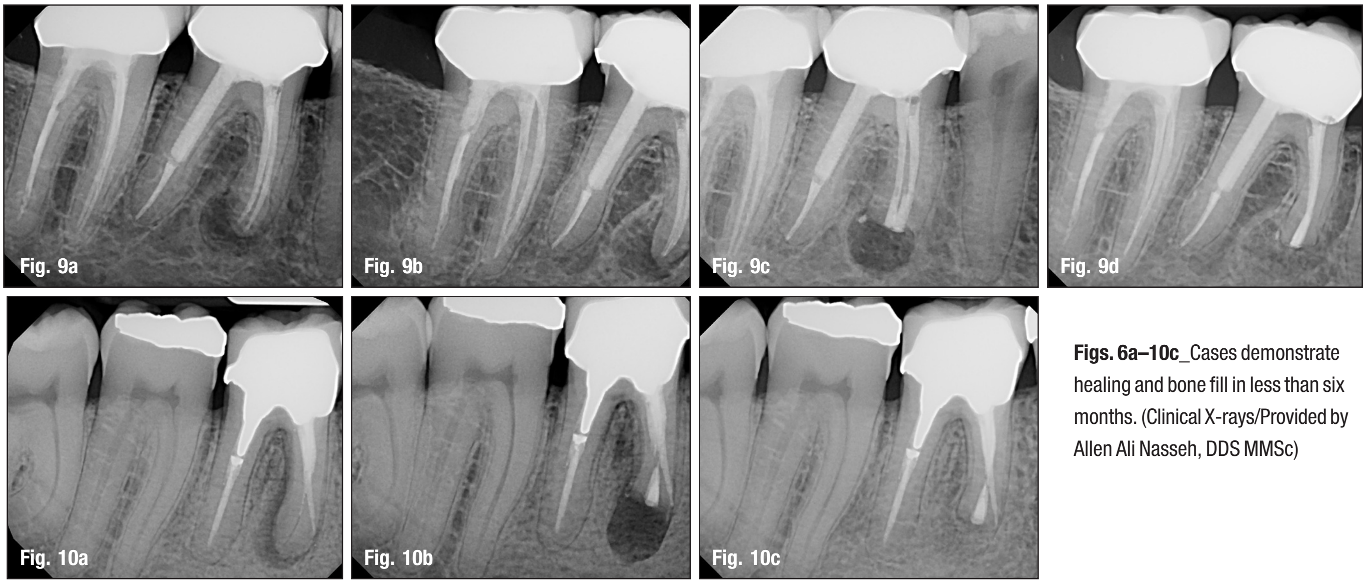
EndoSequence Root Repair material specifically has been created as a white premixed cement for both permanent root canal repairs and apico retrofillings. As a true bioceramic cement, the advantages of this new repair material are its high pH (pH >12.5), high resistance to washout, no-shrinkage during setting, excellent biocompatibility, and superb physical properties. In fact, it has a compressive strength of 50-70 MPa, which is similar to that of current root canal repair materials, ProRoot MTA (Dentsply) and BioAggregate (Diadent). However, a significant upgrade with this material is its particle size, which allows the premixed material to be extruded through a syringe rather than inconsistent mixing by hand and then placement with a hand instrument.

The Clinicians Report (November 2011) published findings on EndoSequence Root Repair Material. Some of its noted advantages as a root repair material were:

- Easier to use and place than previous similar products.
- Good dispenser (tip/syringe) for easy dispensing.
- Radiopaque.
- Mulitple uses for a variety of clinical conditions.
- No mixing required.

Furthermore, their final conclusion was that 95 percent of 19 CR Evaluators stated that they would incorporate EndoSequence Root Repair Material into their practice. Ninety-five percent rated it excellent or good and worthy of trial by colleagues.

Another significant piece of research was published in the Journal of Endodontics, where a research team investigated the antibacterial activity of EndoSequence



Figs. 6a–10c_Cases demonstrate healing and bone fill in less than six months. (Clinical X-rays/Provided by Allen Ali Nasseh, DDS MMSc)

Root Repair material against Enterococcus faecalis. The aim of this study was to determine whether EndoSequence Root Repair material either in its putty form or as a syringeable paste possessed antibacterial properties against a collection of Enterococcus faecalis strains. As a standard, they compared the ESRRM to MTA. Their conclusion was, ESRRM, both putty and syringeable forms and white ProRoot MTA demonstrated similar antibacterial efficacy against clinical strains of E. faecalis.[9]

This research again validated earlier studies that found ESRRM (putty) and ESSRM (paste) displayed similar in vitro biocompatiblity to MTA. Additionally, other studies found that the ESRRM had cell viability similar to Gray and White MTA in both set and fresh conditions.[10]

Even more significant research was published (January 2012) concerning bioceramics in general. In a comparison of endodontic sealers, it was demonstrated that in various moisture conditions within a root canal, iRoot SP (EndoSequence BC Sealer) outperformed all the other sealers. The conclusion of the study was, "Within the experimental conditions of this in vitro study, it can be concluded that the bond strength of iRoot SP to root dentin was higher than that of other sealers in all moisture conditions."[11]

As mentioned previously, the bioceramic material to use in surgical cases is the EndoSequence Root Repair Material (RRM). The ESRRM is available in two different modes. There is a syringeable RRM (very similar to the basic BC Sealer in its mode of delivery) and there is also an RRM putty that is both stronger and malleable. The consistency of the putty is similar to Cavit G. The RRM in a syringe is obviously delivered by a syringe tip but the technique associated with the putty is different.

When using the putty, simply remove a small amount from the room-temperature jar and knead it for a few seconds with a spatula or in your gloved hands. Then start to roll it into a hotdog shape. This is very similar to creating similar shapes with desiccated ZOE or SuperEBA (Bosworth). Once you have created an oblong shape, you can pick up a section of it with a sterile instrument and use this to deliver it where needed (Fig. 8). This is an easy technique for apico retro fills, perforation repairs, and even for resorption defects. After placing the putty into the apical preparation (or defect) simply wipe with a moist cotton ball and finish the procedure.

The cases pictured in Figures 9a to 10c are evidence of how beautifully this technique works. These cases are so significant because they clearly demonstrate the extraordinary healing capability of bioceramics, when used as a repair material. The X-rays display amazing healing and bone fill in the mandible in less than six months.

_Pulp capping with bioceramics

One of the other significant benefits of having bioceramics come premixed in a syringe (EndoSequence Root Repair Material) is the ability for all dentists to now easily treat young patients in need of pulp caps or other pulpal therapies (e.g., pulpotomies). Previously, many specialists considered MTA to be the ideal material for a direct pulp cap because it did not seem to engender a significant inflammatory response in the pulp.

Unfortunately, due to price concerns and the difficulty of placement, this methodology was not universally accepted. However, we now have a true bioceramic material (ESRRM) that not only works well, but is easier to use. It is much easier. Hopefully, this will lead to an increased use of bioceramics in our pediatric patients and help these patients save their teeth. All dentists can benefit from this upgrade in technique.

The technique itself for a direct pulp cap with the bioceramic root repair material is as follows: Isolate the tooth under a rubber dam and disinfect the expo-

sure site with a cotton ball and NaOCl. Apply a small amount of the RRM from the syringe or, take a small amount of the RRM putty from the jar, and place this over the exposure area.

Then, cover the bioceramic repair material with a compomer or glass ionomer restoration. Following the placement of this material, proceed with the final restoration, including etching if required. Single-visit direct pulp capping is now here.

_Future directions and prosthodontic applications

The future promises to be even more exciting in the world of bioceramics. There will be new fast-set (eight to 10 minutes) repair materials introduced, as well as a special bioceramic putty for pediatric use (primary teeth). We have also seen the melding of bioceramic technology into the world of prosthodontic cements, with the introduction of Ceramir Crown & Bridge (Doxa Dental). It is easy to predict that we will see more applications of this technology in different aspects of dental medicine.

In this article, we have introduced a new bioceramic sealer (EndoSequence BC Sealer) that when combined with coated cones offers an exciting new obturation technique (Synchronized Hydraulic Condensation).

The properties associated with the new bioceramic sealer also allow us to be more conservative in our endodontic shaping which ultimately leads to the preservation of natural tooth structure. Surgical applications have also been introduced, and cases shown, which demonstrate the remarkable ability of bioceramics. The future is bright for bioceramic technology and even more exciting for dental medicine._

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roots

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