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ENDODONTIC TRIAD FOR SUCCESS: THE ROLE OF MINIMALLY INVASIVE TECHNOLOGY

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For more than 50 years there has been universal agreement that the triad for endodontic success is shaping canals, cleaning in 3 dimensions, and filling root canal systems. Further, it is globally accepted that 3D disinfection is central to success and has traditionally required a well-shaped canal. Yet, the concept of minimally invasive endodontics (MIE) has ignited a discussion between proponents of well-shaped canals and those who advocate more minimally prepared canals. Although well intended, this shaping shift, alone, will never fulfill the biological objectives for success. To forward the concept of MIE will require a new future that's not about the past, but takes the past into account.

The way forward to better respect the concept of minimally invasive endodontics requires minimally invasive technology that strategically optimizes 3D disinfection and filling root canal systems. This article will examine each pillar that supports the endodontic triad for success and focus on the current and future technologically-driven methods that will better enable 3D cleaning and filling root canal systems. The intention of this article is to invite everyone to pause, pump the brakes, and thoughtfully reflect on how each pillar, individually and in combination, serves to influence the biological objectives for predictably successful endodontics.

SHAPING CANALS

The only current reason to skillfully negotiate, secure, and fully shape any given canal is to create sufficient space to hold an effective reservoir of reagent that, upon activation, can be potentially exchanged into all aspects of the root canal system. Even with this long-standing knowledge regarding the importance of the shape, ongoing debate and lingering controversy continues as to the minimum mechanical requirements that enable any given preparation and its related root canal system to be 3D cleaned and filled ***(Figure 1)***. Over the decades, 2 philosophical points of view have emerged for shaping more restrictive canals.

One widely adopted point of view emphasizes smaller terminal diameters and wider apical tapers, while maximizing remaining dentin in the body of the same canal.[1] Traditionally, a finished preparation is confirmed to have a terminal diameter equivalent to a size 25 file and an apical one-third taper of 10% when each sequentially larger sized file uniformly steps back out of the canal in 0.5 mm increments ***(Figure 2)***. However, in longer, narrower, and more curved canals, or in roots that exhibit deep external concavities, an apical one-third taper of 10% may be anatomically inappropriate ***(Figure 3)***. In these instances, it has

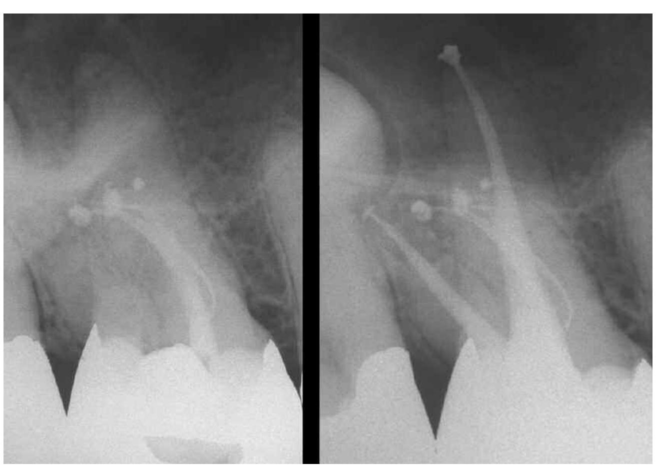


Figure 1. *These radiographic images demonstrate this MB system contains a loop, an anastomosis, and divides apically into 4 portals of exit.*

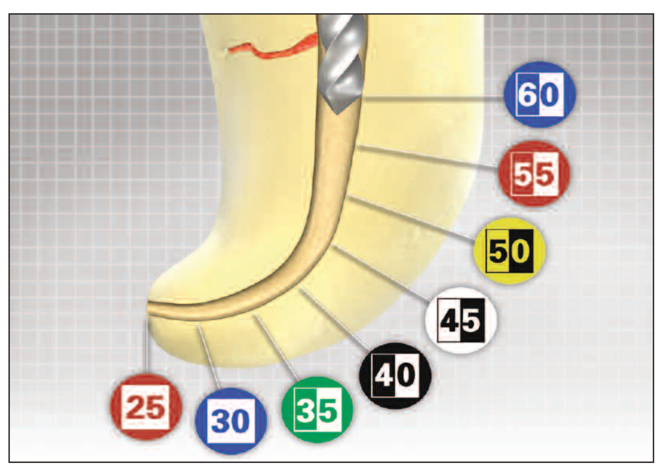


Figure 2. *A graphic illustrates a traditional stepback preparation that has a 10% taper limited to the apical one-third.*

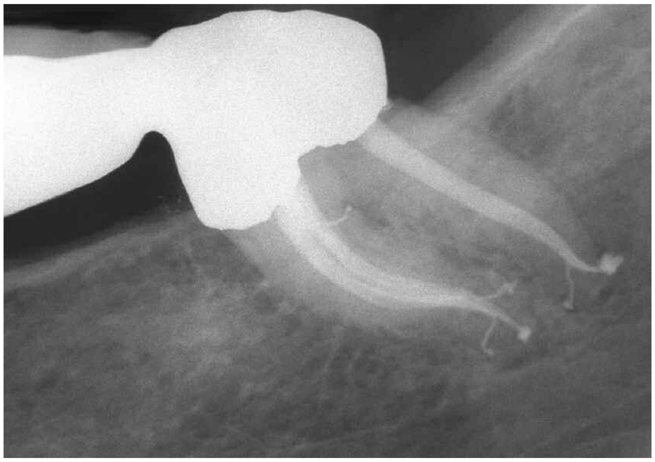


Figure 3. This post-treatment film reveals 3 flowing multiplanar shapes and 6 filled portals of exit. Note the furcal canal.

been shown that a narrower taper of 8% can also safely clean curved canals and their related root canal systems.[2]

The other time-honored preparation method emphasizes the importance of enlarging the terminal diameter of virtually any preparation, regardless of its actual anatomical size, to at least a size 40 file.[3] Emphasis is on working larger D0 diameter files short of length, developing an apical box, and producing a tapered preparation of 4% or 6%. Yet, blocks, ledges, and apical transportations can result when working larger sized, and hence stiffer, files to length, especially in longer, narrower, and more apically curved canals.[4] Further, caution should be exercised when shaping canals that exhibit deeper external root concavities, as overpreparing the body of these canals thins roots and predisposes to iatrogenic events. Appreciate that a size 30/06 or 40/06 fixed tapered file has a large D16 diameter of 1.26 mm or 1.36 mm, respectively ***(Table 1)***.

The international body of research on shaping canals has traditionally demonstrated that preparations must be developed to minimal mechanical parameters in order to potentially exchange intracanal irrigants into all aspects of the root canal system. Further, Baumgartner has shown that a 20/10 preparation is equally clean to a 40/06 preparation ***(Figure 4)***.[5] From the evidence, it could be said that that these 2 schools of thought have defined the boundaries for final shapes that can be theoretically cleaned and filled. In spite of these boundaries, there is emerging advocacy that champions more minimally prepared canals, while failing to address how this alone can 3D clean and fill these canals and their related root canal systems.[6]

To objectively compare commercially available files and the shapes they cut, it would be wise to first review the anatomy of human teeth. With exceptions, the vast majority of teeth range from 19-25 mm in overall length. Most clinical crowns are about 10 mm and most roots range from 9-15 mm in length. If we divide the root into coronal, middle, and apical one-thirds, then each third is between 3 and 5 mm in length, or on average 4 mm ***(Figure 5)***. This means the most important aspect of a file is that portion of its active length that actually extends below the orifice. With so much misinformation, it is informative to compare the cross-sectional diameters of different brands and designs of files along their active portion from D1 to D12 ***(Tables 1 & 2)***.

Another critical consideration that will influence the terminal diameter and taper of the preparation, and hence disinfection, is whether the file has a *fixed* or *variably* tapered design along its active portion. Table 1 provides information regarding files with different D0 diameters and fixed tapered designs; examples of the more popular North American brands with this design include ProFile, GT, Vortex, TF Adaptive files, and Sequence. As was previously stated, caution should be exercised if the decision is to carry a file with a larger D0 diameter and 6% fixed tapered design to the full working length.

File brands that have a variably or progressively tapered design over the active portion of a single file were first introduced in

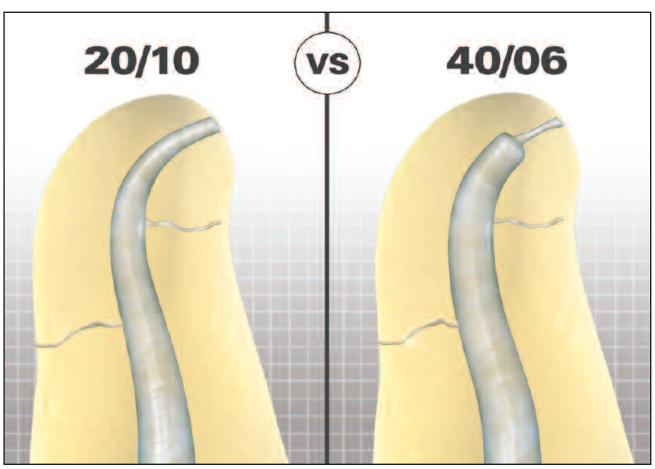


Figure 4. Although problematic, the apical box preparation has been traditionally advocated to prepare a canal with a wider apical diameter and narrower taper.

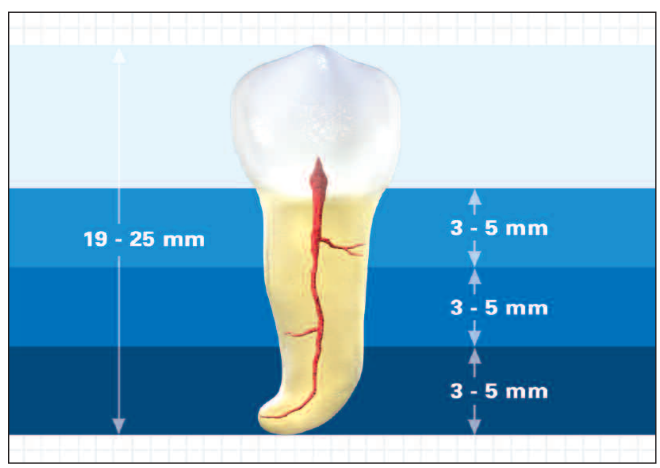
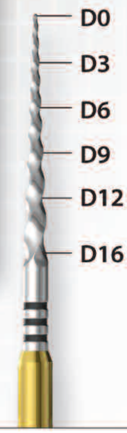


Figure 5. A graphic illustrates the concept of mentally dividing roots into thirds.

FIXED TAPERED FILE DESIGN

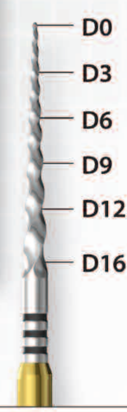
	25/06	30/06	40/04	40/06
D0	0.25	0.30	0.40	0.40
D3	0.43	0.48	0.52	0.58
D6	0.61	0.66	0.64	0.76
D9	0.79	0.84	0.76	0.94
D12	0.97	1.02	0.88	1.12
D16	1.21	1.26	1.04	1.36



Cross-sectional diameters (mm) along the active portion for files with a fixed tapered design.

VARIABLY TAPERED FILE DESIGN

	TruShape 25/06	PTN X2 25/06	PTU/PTG F2 25/08	WaveOne 25/08
D0	0.25	0.25	0.25	0.25
D3	0.42	0.43	0.49	0.41
D6	0.56	0.63	0.67	0.67
D9	0.66	0.84	0.82	0.84
D12	0.72	1.05	0.93	1.00
D16	0.80	1.20	1.05	1.20



Cross-sectional diameters (mm) along the active portion for files with a variably tapered design.

North America by Dentsply Tulsa Dental Specialties (DTDS). Table 2 provides information and specific examples of legally sold file brands with this design, which include TruShape, ProTaper NEXT (PTN), ProTaper Universal (PTU), ProTaper Gold (PTG), and WaveOne. For example, a PTU/PTG 25/08 F2 Finishing file has a fixed taper of 8% from D1-D3, then a decreasing percentage tapered design from D4-D16. With respect for the concept of MIE, the F2 has a D16 diameter of 1.05 mm vs. an alarming 1.53 mm if this same file had a fixed taper of 8% over the entire length of its active portion ***(Figure 6)***. Hence, the concept of MIE is commercially driving 3 viewpoints and related technologies. One viewpoint advocates minimally preparing canals using smaller-sized fixed or decreasing percentage tapered file designs. However, profoundly more meaningful and central to success is minimally invasive technology (MIT) that can exquisitely clean root canal systems, in either fully prepared or minimally prepared canals. Minimally prepared canals and their related root canal systems that can actually be disinfected will, in turn, require advancements in MIT and materials that can predictably fill root canal systems. MIT that focuses on 3D disinfection and filling root canals systems are the breakthrough for MIE and the future of endodontics.

3D Disinfection

Like the extraction, endodontic treatment should be directed toward removing all the pulp, bacteria when present, and related irritants from the root canal system. Further influencing 3D disinfection is to recognize that the files utilized to prepare canals produce a smear layer, which is oftentimes a cocktail containing dentinal mud, pulpal remnants, and microorganisms, when present. Importantly, this smear layer serves to limit or block the exchange of an irrigant into the uninstrumentable aspects of the root canals system.[7] In the quest

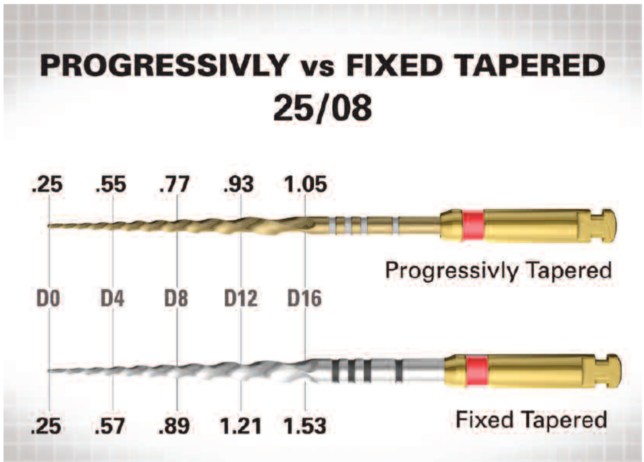


Figure 6. *A PTG Finishing file better respects the concept of minimally invasive endodontics compared to a same-sized file with a fixed tapered design.*

toward complete 3D disinfection, many reagents, devices, and methods have been advocated.

One of the more traditional methods has included dispensing various reagents from a handheld syringe, utilizing a preferred gauge canula. More recently, many so-called final rinse solutions have come to market to presumably better eliminate microorganisms. Over the years, other disinfection methods emerged, including heating reagents, utilizing iontophoresis, pumping an apically trimmed gutta percha master cone in a well-shaped and fluid-filled canal, employing negative pressure irrigation/vacuum devices, activating reagents with ultrasonic *metal* insert tips or sonic *nonmetal* insert tips, and energizing reagents with soft and hard tissue lasers.

Importantly, there has been significant interest in biofilms and their role in endodontic prognosis. A biofilm is a structured community of bacteria enclosed in a protective, sticky polysaccharide matrix that can adhere to any root canal surface. Further, planktonic, or free floating organisms within biofilm fragments, have been observed to disrupt, drift, and reattach to any surface within the root canal system, including dentinal tubules.[8] Logically, 3D cleaning procedures should be directed toward disrupting any given biofilm, breaking up this matrix, and moving this infected mass into solution so it can be eliminated from the endodontic space.

Active irrigation is intended to initiate fluid hydrodynamics and holds significant promise to improve disinfection. There is increasing endodontic evidence to support that fluid activation plays a strategic role in cleaning and disinfecting all aspects of the root canal system, including dentinal tubules, lateral canals, fins, webs, and anastomoses.[2,9-11] The greatest focus today is on how to safely activate any given solution to maximize the *hydrodynamic phenomenon* in both well-shaped and minimally prepared canals. There are several emerging methods that are receiving attention and are purported to effectively activate an intracanal solution.

HYDRODYNAMIC DISINFECTION

The EndoActivator system is comprised of a cordless handpiece and variously sized polymer tips ***(Figure 7a)***. This technology utilizes sonic energy to drive a preselected tip, which in turn, activates various intracanal reagents, producing a vigorous hydrodynamic phenomenon in well-shaped canals. A strong, flexible, and noncutting vibrating tip generates fluid activation and intracanal waves, which then fracture, creating bubbles that oscillate within any given solution ***(Figure 7b)***. These bubbles expand and become unstable, then collapse and implode. Each implosion produces shockwaves that dissipate at 25,000 to 30,000 times per second.[9]

Shockwaves serve to powerfully penetrate, break up biofilms when present, and wipe surfaces clean. Imploding bubbles desirably increase the temperature and further generate significant pressure on an intracanal irrigant, which in a small anatomical space, serves to promote surface cleaning.[8-9] During use, the action of the EndoActivator tip frequently produces a cloud of debris that can be observed within a fluid-filled pulp chamber. Research has shown this technology is able to remove the smear layer, debride into the deep lateral anatomy, and dislodge biofilm clumps within curved mesial canals of molar teeth ***(Figure 7c)***.[2,10-11]

Another powerful method to eradicate microbes utilizes photoactivated disinfection (PAD). Clinically, this technique involves dispensing a photosensitizer dye, such as tolonium chloride, into a well-shaped canal. The assumption with PAD is that the intracanal reagent can reach and target bacteria by binding to or entering any given microbial cell. Prof. Gulabivala and his team at the Eastman Dental Institute have shown that this can be facilitated utilizing the EndoActivator.[12] A low power diode laser then emits light and creates a cascade of energy transfer in the photosensitizer, which in turn, releases singlet oxygen. Singlet oxygen is a protoplasmic poison, causes lethal damage, and implodes the marked bacterial invaders.[8]

The challenge is to activate any given reagent so it will penetrate, reach, and kill bacteria. Compounding the challenge to eliminate biofilms is that they have the ability to hide within an anatomically complex space, further complicated in that they are protected by their own secretions. On the horizon, the Toronto group led by Prof. Anil Kishen has been working on advanced disinfection strategies for cleaning the uninstrumentable portions of the root canal system. This work is focusing on utilizing antibacterial nanoparticles, antimicrobial photodynamic therapy, and laser-assisted root canal disinfection methods.[13]

3D Disinfection in Minimally Prepared Canals

New minimally invasive 3D disinfection technologies have recently come to market that do not require canal preparation as traditionally advocated. At the Arizona Center for Laser

Dentistry, Dr. Enrico DiVito and his team ingeniously developed Photon Induced Photoacoustic Streaming (PIPS) ***(Figure 8)***.[14] This laser-activated disinfection method often only requires any given canal be prepared to a size 20 file. The unique tapered and striped PIPS tip is placed stationary in the pulp chamber only. When activated, PIPS creates non-thermal photoacoustic shockwaves, which travel 3D, even into the anatomically complex apical regions. Scientific evidence confirms PIPS eliminates both planktonic and biofilm contaminates and sterilizes more than 1000 µm deep into the dentinal tubules, without damaging root canal morphology.[15]

Another 3D disinfection technology that is imminently coming to market has been developed by Sonendo and is commercially termed GentleWave ***(Figure 9)***. In this method, an access cavity is prepared and more restrictive canals are catheterized to a size 15 file, or in more open canals, no instrumentation is required at all. Subsequently, the GentleWave handpiece is connected to the cavosurface of an endodontically accessed tooth. Treatment reagents flow through this closed system, creating multisonic energy in the form of specific wide spectrum wavelengths using different frequencies. Collaborative research has shown that this disinfection method can 3D clean a canal, the lateral anatomy, and related dentinal tubules.[16]

Filling Root Canal Systems

Virtually all obturation methods scientifically validated, utilized, and reported have been analyzed within the preparation boundaries previously identified. Specifically, warm gutta percha 3D filling methods can be effectively utilized in virtually any well-shaped canal ***(Figure 10)***.[17] The most popular methods include vertical condensation, single-wave condensation, and carrier-based obturation. At this moment of endodontic development and financial practicality, only a single cone technique or a syringeable extrusion method exists for filling a minimally prepared canal. It would be wise to recall the avalanche of endodontic failures that resulted when single cones, silver points, and carrier-based obturators were utilized in underprepared canals.[4]

To date, there is no mainstream method to predictably fill any given minimally prepared or essentially noninstrumented canal. Certainly, work has been and is being done utilizing different

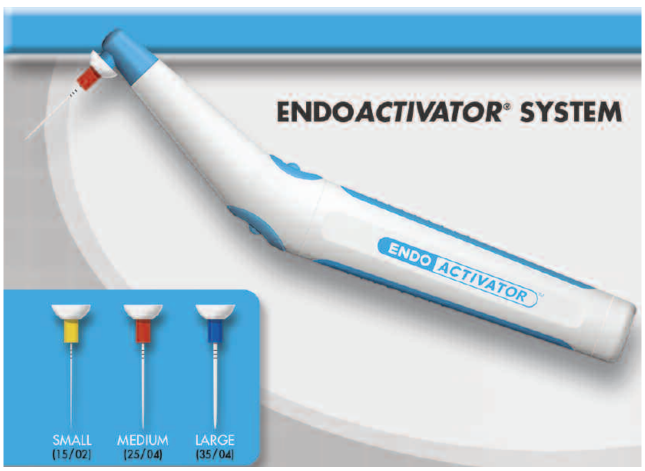


Figure 7a. The EndoActivator system is designed to safely and vigorously exchange intracanal reagents into the root canal system anatomy.

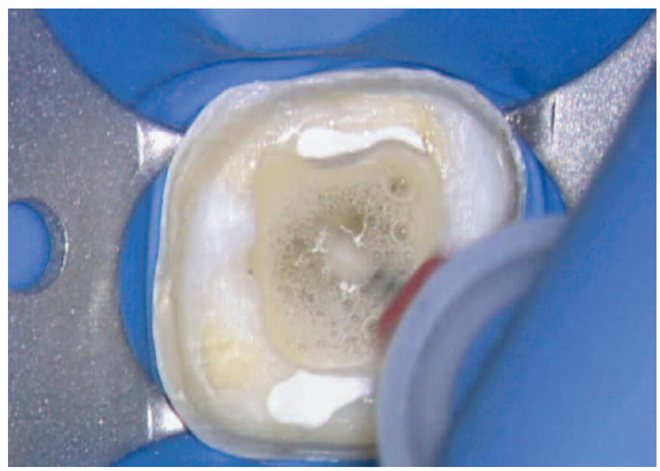


Figure 7b. This image shows the EndoActivator initiating vigorous fluid activation.

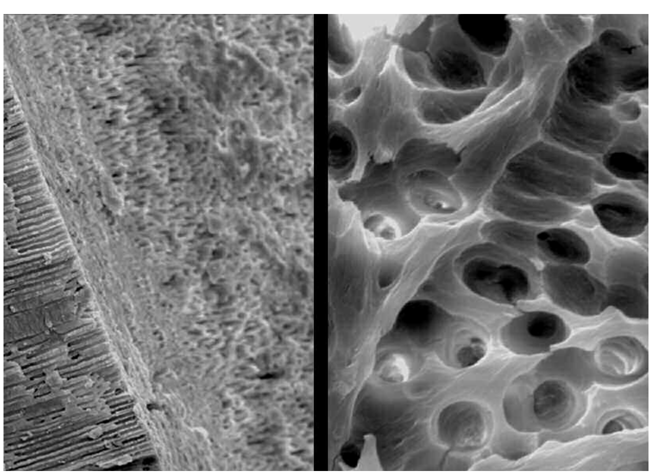


Figure 7c. SEM images provide evidence that the EndoActivator system can clean root canal systems (Figure 7c courtesy of Dr. Grégory Caron; Paris, France).

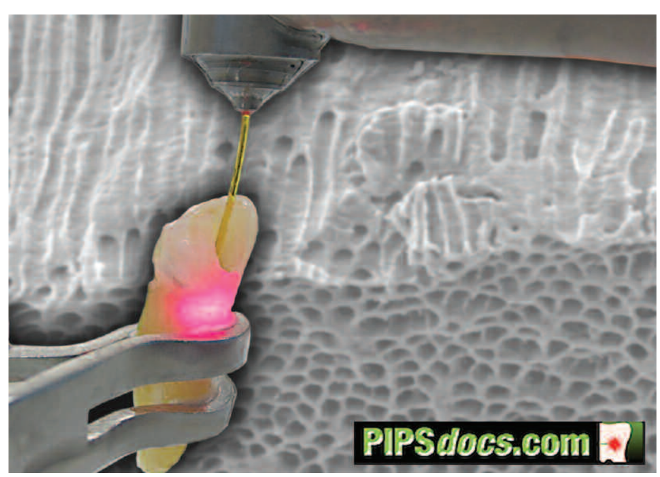


Figure 8. An SEM image provides histological evidence that the PIPS method 3D cleans canal surfaces, tubules, and root canal system anatomy.

Figure 9. *Evidence has shown that GentleWave technology can remove the smear layer, eliminate tissue, and clean deep into the dentinal tubules.*

Figure 10. *This post-treatment film demonstrates that effective access is essential to identify, shape, and fill these 5 root canal systems.*

materials, technologies, and methods. However, when the CEO of a company that has developed noninstrumentation 3D disinfection technology was asked how a dentist could predictably and 3D fill such a minimally prepared canal, he stated, "Get anything you can to length that will produce a white line on a radiograph and the insurance company will pay." This tongue-in-cheek answer readily acknowledges that there is a need to perfect a method to more predictably 3D fill underprepared, minimally prepared, or canals not prepared at all.

FUTURE

Dr. Nathan Li and his team at Healthdent recently developed system-based gutta percha master cones (GPMCs) for well-shaped canals prepared with the most popular file brands. These GPMCs offer superior sizing and formulation and were recently launched through Charles B. Schwed. Fortuitously, Healthdent's proprietary methods represent a breakthrough by providing an extended heat wave through the gutta percha master cone. Further, Healthdent's work in nanotechnology is leading to the development of methods to revolutionize carrier-based obturation, as we know it. Effort has focused on developing a game-changing method to 3D fill root canals and their related systems, whether minimally shaped or not shaped at all ***(Figure 11)***. This recent work is showing promise to unlock a new future for MIE.

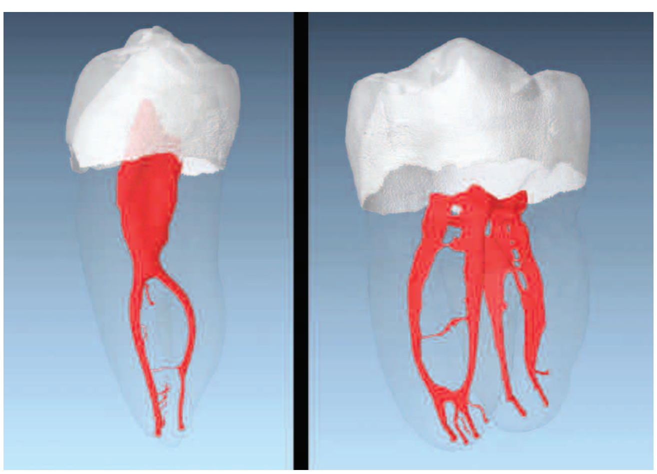


Figure 11. *These µCT images illustrate that advanced technologies are essential to fully treat root canal systems (Courtesy of Dr. Frank Paque; Zurich, Switzerland).*

The above mentioned innovations, namely, methods to fill minimally prepared canals or canals not prepared at all, are absolutely essential in order to truly bring in a new era of better fulfilling the concept of MIE, which in turn will redefine the triad for endodontic success. MIE is not simply an argument about the size of the access cavity, or whether the canal should be a certain dimension at any given level. The concept of MIE must also focus on the necessity of eliminating vital or necrotic tissue from avascular root canal system during and after pulp death. Minimally invasive canal preparation, alone, is not MIE when primary treatment fails, requiring, at times, coronal disassembly, nonsurgical retreatment, surgical correction, or extraction.[4]

CONCLUSION

There is significant change coming, yet again, to the specialty field of endodontics. Regardless of how compelling any given technology and method is, it only represents a true breakthrough if all endodontic mandates can be predictably accomplished utilizing existing available technologies. So-called minimally invasive files systems are meaningless unless their commercial introduction and advocacy is accompanied by affordable companion technologies that offer genuine potential to better fulfill the endodontic triad for success. Until then, we would all be wise to recall Schilder's clarion cry, "Make yourself the patient and you will have the answer." ▲

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