Hydrodynamic Disinfection "Tsunami" Endodontics

Clifford J. Ruddle

Introduction

There are enormous differences in opinion regarding the potential to 3-dimensionally clean a root canal system. Elimination of pulpal tissue, bacteria (when present), and their related breakdown products is directly influenced by a series of procedural steps that comprise start-to-finish endodontics. Regrettably, no single beacon of light brightly illuminates the most proven clinical techniques essential for predictably successful endodontics. A review of the literature reveals virtually no agreement on a variety of fundamental clinical issues. As a single example, bacteria are ubiquitous in endodontically failing teeth, yet there is great controversy regarding the very methods used that directly influence their elimination.

Debate is ongoing regarding the irrigants, their sequence of use, or the intracanal volume required to promote 3-dimensional cleaning. Confusion abounds as to the ideal strength, optimal temperature, or the extent of time required for any given reagent to fulfill its intended purpose. The debridement and disinfection of a root canal system further depends on the apical one-third taper and the terminal diameter of the final preparation; yet again, there is no consensus on how these interrelated preparation objectives serve to directly influence the exchange of any given irrigant. Even though rational treatment approaches are available and precise techniques have been perfected, the dominant clinical reality is the best that endodontics has to offer is only sporadically delivered in everyday practice.

This article will briefly review the rationale for treatment and the endodontic objectives. Particular emphasis will be placed on those factors that influence disinfection. The focus of this article will be on hydrodynamic disinfection and a clinical technique designed to facilitate this process.

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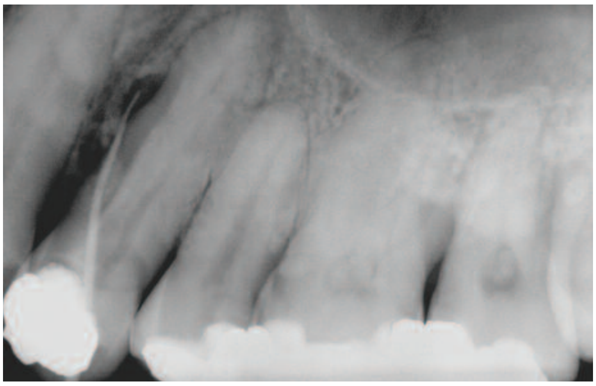

Figure 1a: A preoperative film of a maxillary first bicuspid. A gutta-percha cone traces a sinus tract and points to a lesion of endodontic origin.

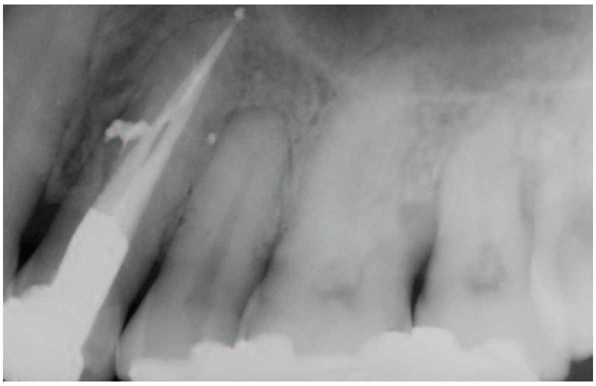

Figure 1b: A 10-year post-treatment radiograph reveals excellent healing and confirms the importance of treating root canal systems.

Rationale for treatment

Pulpal injury frequently leads to irreversible inflammatory conditions that potentially progress to ischemia, infarction, necrosis, and ultimately complete pulp death. This phenomenon originates in a space exhibiting infinite anatomical configurations and intricacies along its length.[1] Root canal systems contain branches that communicate with the attachment apparatus furcally and laterally, and often terminate apically into multiple portals of exit (POEs).[2] Consequently, any opening from the root canal system to the periodontal ligament space should be thought of as a POE through which potential endodontic breakdown products may pass. Radiographically, it is fundamental to associate that lesions of endodontic origin (LEOs) arise secondary to pulpal breakdown and form adjacent to the POEs.[3] Improvement in the diagnosis and treatment of LEOs occurs with the recognition of the interrelationships between pulpal disease flow and the egress of irritants along these anatomical pathways (Figures 1a and 1b).[4]

Endodontic Objectives

Except in rare instances, LEOs will routinely heal following tooth extraction because this procedure not only removes the tooth, but importantly serves to eliminate 100% of the contents of the root canal system. Like the extraction, endodontic treatment should be directed toward removing all the pulp, bacteria (when present), and related irritants from the root canal system. The biological objectives of endodontic treatment are to eliminate the tooth as a source of irritation to the attachment apparatus. Schilder was the first to propose a set of mechanical objectives that promote 3-dimensional cleaning and obturation of the root canal system. Discounting hopeless periodontally involved teeth and radicular fractures, complete endodontic treatment can approach 100% success.[5]

Properly restoring the endodontically treated tooth is essential for long-term success, and is what Southard termed "the rest of the seal." (Figure 2).[6]

One of the more significant advances in the years immediately ahead will be the development of specific methods that will promote 3-dimensional cleaning. Innovative technologies will continue to emerge that will move the field of endodontics ever closer toward achieving the biological goal of complete debridement and disinfection.

Factors Influencing Disinfection

In the context of this article, the words disinfection and cleaning will be used interchangeably and will refer to complete debridement, the elimination of the smear layer, and the disruption and removal of the biofilm from all aspects of the root canal system.

Debridement refers to the elimination of the pulp tissue, bacteria (when present), and their related irritants from the root canal space. A smear layer forms on the walls of the canal as a byproduct generated by any file utilized to cut dentin. Dentinal debris, in combination with a reagent, forms mud. Dentin mud should be considered a pathogenic cocktail, as it potentially harbors remnants of pulpal tissue, bacteria, and their related irritants. Bacteria are well-known to invade the dentinal tubules, and dentin mud has been shown to frequently block the lateral anatomy (Figure 3).[7] This distinction is made, as most colleagues think of a blocked canal as an apical misadventure that prevents a small-sized flexible file from easily sliding to, and minutely through, the terminus of the canal.[8]

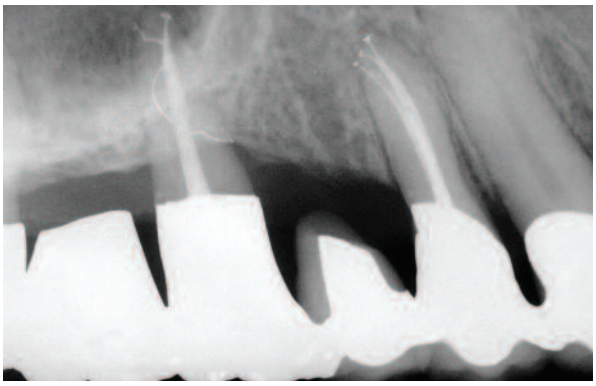

Figure 2: Shaping canals facilitates both 3-dimensional cleaning and obturation. Complete endodontic treatment is the foundation for perio-prosthesis.

Recently, there has been significant interest in biofilms and their role in endodontic prognosis.[9-10] A biofilm is a structured community of bacteria enclosed in a protective, sticky polysaccharide matrix that adheres to a root canal surface. Further, biofilm fragments have been observed to disrupt, drift, and reattach to any surface within the root canal system, including dentinal tubules.[11]

On the external tooth surface, these biofilms are referred to as plaque. The methods commonly used to remove dental plaque potentially prognosticate the best approaches for removing an intracanal biofilm. Logically, 3-dimensional 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. The following factors, independently and in combination, serve to influence cleaning, and ultimately, treatment outcomes. These factors will be categorized into endodontic procedures, cleaning reagents, and hydrodynamic disinfection.

Endodontic Procedures

A series of procedural steps comprise start-to-finish endodontics. Those procedures that directly influence cleaning will be identified, and their role in cleaning the root canal system emphasized.

Access

Preparing the endodontic access cavity is a critical step in a series of procedures that potentially leads to the 3-

Figure 3: This animation image demonstrates that shaping files produce dentin mud. Irrigation potential is limited when the lateral anatomy is obstructed.

Figure 4a: A photo demonstrates access through a full veneer casting. Note this mandibular molar has 3 mesial orifices.

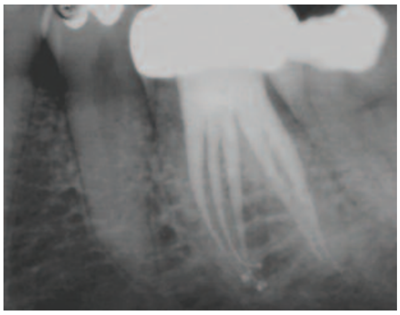

Figure 4b: A post-treatment film demonstrates straightline access and complete endodontics.

dimensional cleaning and obturation of the root canal system.[12] Access cavities should be cut so the pulpal roof, including all overlying dentin, is removed. The size of the access cavity is dictated by the anatomical position of the orifice(s). The axial walls are extended laterally such that the orifice(s) is just within this outline form. The internal walls are flared and smoothed to provide straightline access to the orifice and the underlying root canal system. Cleaning and shaping potentials are improved when instruments conveniently pass through the occlusal opening, effortlessly slide down smooth axial walls, and are easily inserted into a preflared orifice. Spacious access cavities are an opening for shaping and cleaning procedures (Figures 4a and 4b).

Shaping Facilitates Cleaning

Schilder outlined the mechanical objectives for preparing a canal that, when fulfilled, promote the biological objectives required for pre-dictably successful results. Common sense tells us that no 2 objects can occupy the same space at the same time. As such, all organic material must be eliminated to make space available for obturation materials. The breakthrough is to understand that un-shaped canals cannot be cleaned. Shaping facilitates cleaning by removing restrictive dentin, which allows for a more effective reservoir of irrigant. Shaping is the de-velopment of a "logical" cavity preparation that is specific for the anatomy of any given root. It is essential to appreciate that fully shaped canals hold a larger volume of irrigant that can potentially circulate, penetrate, and clean all aspects of the root canal system.[13-14]

Preparation Technique

The preparation technique utilized will influence irrigation and cleaning potential. As an example, the step-back, crown-down, and pre-enlargement techniques have been advocated for shaping canals. Each technique has been described in different ways, has something to offer, and was developed to advance canal preparation methods.[15] Although each technique can theoretically produce the same final shape, each method is very different and has been designed to prepare a general region within the canal in a precise sequence. A major advantage of the pre-enlargement technique is that procedures are initially directed toward removing restrictive dentin in the coronal and middle thirds of the canal.[13] Fortuitously, a pre-enlarged canal holds a more effective volume of irrigant, which in turn improves the potential for its exchange when preparing the apical one third of the canal.

The ability to clean a root canal system is further influenced by the cross-section of a file. Clinical evidence is growing that shows that files with radial lands tend to scrape, burnish, and trap more mud into the lateral anatomy, whereas files with cutting edges tend to cut dentin more cleanly. Two additional factors that influence the exchange of an irrigant and its potential to clean a root canal system are the taper of the preparation and the terminal diameter of a canal.[16] The apical taper and terminal diameter of any given preparation are critically interrelated and serve to influence the exchange of irrigant, and hence, the potential to clean.

The mechanical techniques employed need to respect the anatomy and should not needlessly over-enlarge the apical region of the canal. Dentists need to completely understand and fully appreciate that it is the files that shape a canal, but it is the irrigants that serve to clean a root canal system (Figures 5a and 5b).

Cleaning Reagents

The intracanal reagents and their sequence of use are significant factors that influence cleaning. Scientific investigations are increasingly being directed toward identifying the best reagents and their optimal strength and ideal temperature.[17] Importantly, protocols must be

Figure 5a: This animated molar image demonstrates typical molar anatomy. Note the fins, anastomoses, and multiple portals of exit.

Figure 5b: This image shows that well-shaped canals encourage the exchange of irrigant. Active irrigation promotes 3-dimensional cleaning and complete endodontics.

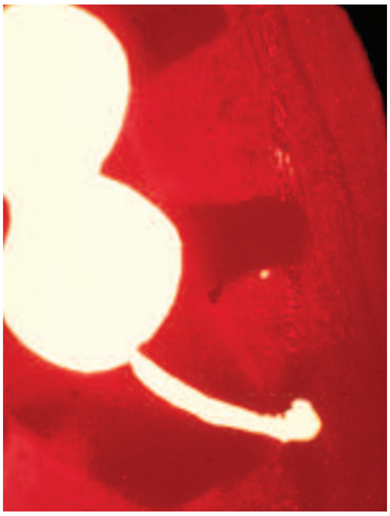

Figure 6: A histological section from a maxillary bicuspid confirms that files shape canals, but it was the NaOCl that cleaned out the lateral canal. (Courtesy of Dr. Gery Grey, Greenbrae, Calif.)

developed to specify the frequency, volume, and time required for any given solution to clean a root canal system. The potential to debride and disinfect is further influenced by alternating between specific types of intracanal solutions, or using them in combination.

Recently, what are termed final rinse solutions have emerged and their use advocated to enhance root canal cleaning. Examples of final rinse solutions include Bio-Pure MTAD Antibacterial Root Canal Cleanser (DENTSPLY Tulsa Dental Specialties), SmearClear (Sybron-Endo), and chlorhexidine (CHX). Regardless, the most important reagents that are routinely used to clean a root canal system are sodium hypochlorite (NaOCl) and ethylenediaminetetraacetic acid (EDTA [Roth International]).[18-20] The following will describe these intracanal solutions utilized to achieve 3-dimensional cleaning.

Sodium Hypochlorite (NaOCl)

NaOCl is a powerful and inexpensive irrigant that can potentially destroy spores, viruses, and bacteria, and importantly, has been shown to digest vital and necrotic pulp tissue from all aspects of the root canal system (Figure 6).[21] Studies have shown that warming NaOCl to approximately 60°C (140°F) significantly increases the rate and effectiveness of tissue digestion.[22] The potential for an irrigant is maximized when it is heated, flooded into shaped canals, and given ample time to work.[23-24] The frequency of irrigation is dictated by the amount of work that a particular instrument performs. In general, irrigate more frequently in tighter, longer, and more curved canals, and especially if the system exhibits unusual anatomy. There is no agreement regarding the volume of irrigant required to clean a root canal system.

However, when an instrument is placed into a relatively small canal, the file tends to displace the irrigant. When the instrument is withdrawn, the irrigant flows back into the space the file occupied.

EDTA

Chelating agents containing EDTA are used to negotiate smaller-diameter canals and to remove the smear layer from the walls of a preparation. In general, the purpose of a viscous chelator is to lubricate, emulsify, and hold debris in suspension when initially negotiating and securing canals. The purpose of an aqueous chelator is to remove the smear layer during and after root canal preparation procedures. EDTA is a surfactant, which serves to lower surface tension, improving an irrigant's potential to circulate and penetrate. An aqueous 17% solution of EDTA flooded into a well-shaped preparation for 1 minute, after canal preparation procedures, has been shown to remove the smear layer.[25-26] Importantly, studies show that alternating between solutions of NaOCl and EDTA during canal preparation procedures reduces the accumulation of debris and results in cleaner canals (Figure 7).[27-29] An aqueous solution of EDTA promotes removal of the smear layer, which is well known to block the dentinal tubules and lateral anatomy.

Logically, if the smear layer is removed, then potentially a tighter adaptation between the obturation materials and the dentinal walls of the preparation is possible.[30]

Passive/Active Irrigation

Passive irrigation is initiated by slowly injecting an irrigant into a canal. In this method, irrigant is passively dispensed into a canal through a variety of different gauged and flexible canulas. The canula is loose in the canal, which allows the irrigant to reflux and move debris coronally. Smaller gauged canulas can be chosen to achieve deeper

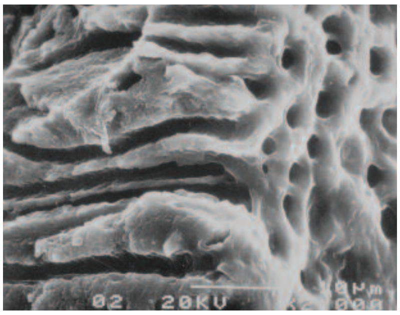

Figure 7: An SEM photograph demonstrates that canals prepared with heated, full-strength NaOCl are clean. Note the tubules are free of organic debris. (Courtesy of Dr. Elio Berutti, Torino, Italy.)

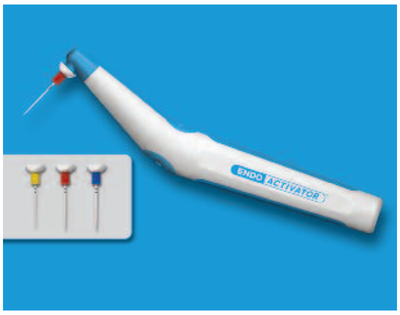

Figure 8: The EndoActivator System is designed to energize the hydrodynamic phenomenon safely and vigorously.

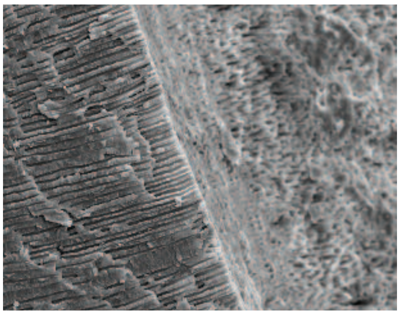

Figure 9a: An SEM image at 500x provides evidence that the Endo-Activator System achieved complete debridement in this well-shaped canal.

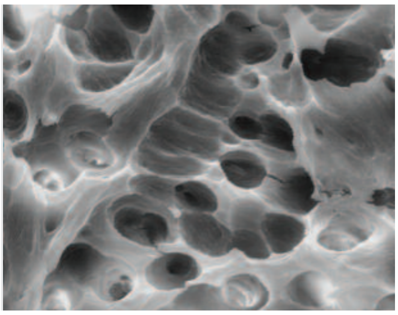

Figure 9b: An SEM image at 2,000x reveals deep lateral cleaning and that the EndoActivator System disrupted both the smear layer and biofilm. (Figures 9a and 9b courtesy of Dr. Grégory Caron, Paris, France.)

and more effective placement.[31] Certain canulas can be selected that dispense irrigant through their most distal end, whereas other canulas deliver irrigant through a closed-ended side port delivery system.[32] Slowly injecting irrigant in combination with continuous hand movement will virtually eliminate NaOCl accidents. Passive irrigation has limitations because a static reservoir of irrigant restricts the potential for any reagent to penetrate, circulate, and clean into all aspects of a root canal system.

Active irrigation is intended to initiate fluid hydrodynamics and holds significant promise to improve cleaning into all aspects of the root canal system. There is increasing endodontic evidence to support that fluid activation, in well-shaped canals, plays a strategic role in debridement and disinfection into all aspects of the root canal systems, including dentinal tubules, lateral canals, fins, webs, and anastomoses.[33-35] The greatest focus today is how to activate any given solution to maximize the hydrodynamic phenomenon. The traditional methods have included warming a reagent utilizing heat transfer devices, vibrating active and nonactive metal instruments with ultrasonic energy, using electrochemically activated solutions, or gently pumping well-fitting gutta-percha master cones to displace and exchange any given reagent.

Several emerging methods are receiving attention and are purported to activate an intracanal solution. These methods include the NaviTip FX canula (Ultradent Products), the new plastic rotary F Files (Plastic Endo), negative pressure or vacuum irrigation devices,[36] and ultrasonically driven metal canulas.[37] Regardless of the specific method, the objective is to enhance the exchange of an intracanal irrigant.

Another method to inactivate microbes utilizes photoactivated disinfection (PAD).[11] Clinically, this technique involves dispensing a photosensitizer solution such as tolonium chloride into a wellshaped canal. This intracanal irrigant targets specific bacteria by binding to or entering these microbial cells. A low-power diode laser is utilized to hit the marked microbe and inactivate these invaders. With all the methods identified, the challenge is still to reach, penetrate, and kill bacteria, which are well-known to protect themselves within dentinal mud, their own secretions, and biofilms. Compounding the challenge to kill microorganisms is their ability to hide within an anatomically complex space. The hydrodynamic phenomenon has been identified as perhaps the only way

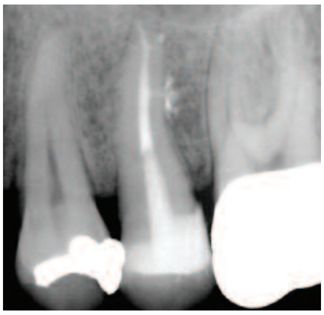

Figure 10: This maxillary second bicuspid demonstrates exquisite and complete endodontics. The EndoActivator System was utilized to produce hydrodynamic irrigation. (Courtesy of Dr. Robert H. Sharp, Sacramento, Calif.)

Figure 11: Custom EndoActivator barrier sleeves are designed to slide over the entire handpiece, including the driver.

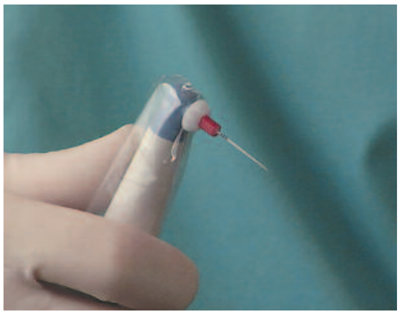

Figure 12: The activator tip is selected, is placed over the barrier-protected driver, and will snap on firmly to promote a secure connection.

to induce biofilm adherence failure.[11,38] The following will identify a new, safe, and easy way to powerfully generate hydrodynamic agitation of any given intracanal solution.

Hydrodynamic Disinfection

The EndoActivator System (Advanced Endodontics) comprises a handpiece and variously sized polymer tips (Figure 8). This sonically driven system is designed to safely activate various intracanal reagents and vigorously produce the hydrodynamic phenomenon. Importantly, sonic activation has been shown to be an effective method to improve disinfection.[39-40] In well-shaped canals, this new technology is intended to provide a safer, better, and faster method to disinfect a root canal system compared to other currently available methods. Research has shown that the Endo-Activator System is able to debride completely into the deep lateral anatomy, remove the smear layer, and dislodge biofilm clumps within the curved canals of molar teeth. (Figures 9a and 9b).[41] Additionally, hydrodynamic activation provides a method to more effectively adapt or eliminate stubborn-to-remove calcium hydroxide from more complex anatomical areas within the root canal.[42]

Further, this technology may be used in straight or more curved canals to deliver mineral trioxide aggregate (ProRoot MTA [DENTSPLY Tulsa Dental Specialties]) into immature teeth exhibiting blunderbuss canals, or into perforating pathological or iatrogenic defects. In the retreatment situation, clinical trials have shown that the EndoActivator System serves to break up and dislodge remnants of previously placed obturation materials.

In a well-shaped canal, the clinical efficacy of the Endo-Activator is immediately appreciated. During use, the action of the EndoActivator tip frequently produces a cloud of debris that can be observed within a fluid-filled pulp chamber. The primary function of the EndoActivator is to produce vigorous intracanal fluid agitation through acoustic streaming and cavitation. This hydrodynamic activation serves to improve the penetration, circulation, and flow of irrigant into the more inaccessible regions of the root canal system.[43]

Cleaning root canal systems provides an opening for 3-dimensional obturation and long-term success (Figure 10). The following will describe this technology and how to integrate the EndoActivator System easily into everyday practice.

EndoDriver Handpiece

The EndoDriver handpiece comprises a cordless, contraangled, and ergonomic sonic handpiece that drives the EndoActivator tips. The handpiece is operated by depressing the light-touch ON/OFF switch that activates the strong and flexible polymer tips. The 3-speed sonic motor switch provides options of 10,000, 6,000, and 2,000 cycles per minute (cpm). When the driver is activated, the power defaults to 10,000 cpm, which is the recommended speed to maximize debridement and disruption of the smear layer and biofilm. Ultimately, the other speeds are selected based on different applications and the power needed to effectively accomplish those clinical tasks. The sonic motor is energized by a single AA alkaline or lithium battery. Depending on use, periodically install a new, fully charged battery to ensure optimal performance. For infection control, custom protective barrier sleeves have been designed to slide easily over the entire handpiece, including the driver (Figure 11). It is important not to autoclave or submerge the handpiece in cleaning solutions; rather, simply wipe down the handpiece, as desired, with an appropriate disinfectant.

EndoActivator Tips

The EndoActivator tips have an easy snap-on/snap-off design and are color-coded yellow, red, and blue,

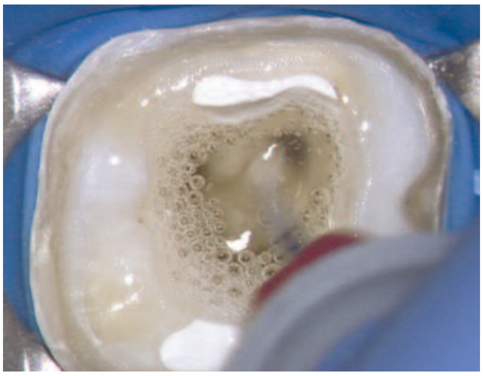

Figure 13: This clinical image shows the EndoActivator System in use. Note the fluid activation and appreciate the potential for enhanced cleaning.

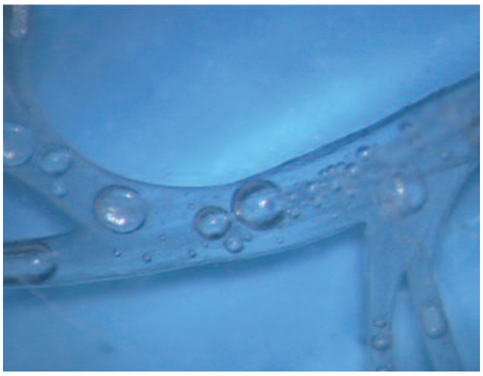

Figure 14: This image depicts a simulated root canal system. The activator tip is used with a pumping motion to produce vigorous hydrodynamics.

corresponding to small, medium, and large sizes, respectively (Figure 8). Specifically, the yellow, red, and blue colorcoded activator tips closely correspond to file nomenclature sizes 20/02, 25/04, and 30/06, respectively. The tips are made from a medical grade polymer, are strong and flexible, and are 22 mm long. Importantly, the polymer tips will not cut dentin, and as such, will not ledge, apically transport, or perforate a canal. The bowl-shaped clean guard serves to consolidate the protective barrier. Each activator has orientational depth gauge rings positioned at 18, 19, and 20 mm. The EndoActivator tips are disposable, single-use devices that should not be autoclaved. At times, the orthodontic Bird Beak Pliers (Hu-Friedy) can be used to place a smooth curve on any size tip to facilitate its placement. The EndoActivator tip selected is placed over the barrier-protected driver and is simply snapped on to secure its connection to the handpiece (Figure 12).

Tip Selection

In fully prepared canals, a tip is selected that fits loosely and to within 2 mm of working length. A loose tip will be free to move, enhancing irrigation dynamics.[35] An underprepared canal or selecting a tip that is too large will serve to dampen or restrict tip movement, which in turn will limit its ability to agitate a solution. The vibrating tip is moved up and down in short, 2-to-3-mm vertical strokes to synergistically optimize a powerful hydrodynamic phenomenon.

In general, 10,000 cpm has been shown to optimize debridement and promote the disruption of the smear layer and biofilm.[41] When the clinical procedure has been completed, support the contra-angled neck of the handpiece, and remove the attached activator tip. Together, the activator tip and barrier sleeve should be discarded.

Clinical Application

Although previously mentioned in this article, the importance of shaping canals must be re-emphasized. Well shaped and fully tapered canals hold an effective reservoir of irrigant that, when activated, can potentially circulate, penetrate, and digest tissue, and further serve to dislodge debris from all aspects of the root canal system. When utilizing the EndoActivator System, vigorous fluid agitation will be clinically observed within the pulp chamber (Figure 13). Although this turbulence is an exciting observation, scientific investigation is required to understand the extent of this phenomenon within a well-shaped canal.

As such, to appreciate better the hydrodynamic phenomenon below the orifice, various scientific experiments have been and are being conducted to visualize the results of cavitation, acoustic streaming, as well as primary and secondary streaming within a root canal system (Figure 14).[34-35,44] The Machtou group has shown the benefits of the Endo-Activator to debride, remove the smear layer, and disrupt biofilms.[41] The hydrodynamic phenomenon results when a vibrating tip generates fluid activation and intracanal waves. As an example, in the physical world, underwater seismic activity releases energy that can induce a large wave formation called a tsunami. In the endodontic world, the metaphor is that vibratory energy within a well-shaped and fluid-filled canal serves to induce intracanal waves. Random waves fracture, creating bubbles that oscillate within any given solution. These bubbles expand and become unstable, then collapse in what is termed an implosion. Each implosion radiates miniature tsunamis, or shockwaves, that dissipate at 25,000 to 30,000 times per second.[37] Shockwaves serve to powerfully penetrate and break up potential bacterial-infested biofilms, and wipe surfaces clean. Imploding

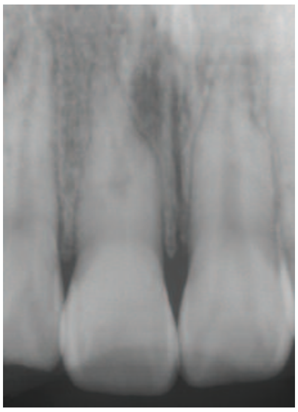

Figure 15a: A radiograph of this endodontically involved maxillary right central incisor reveals coronal calcification and middle one third resorption.

Figure 15b: The post-treatment film demonstrates the result of shaping, activating fluids, and 3-dimensional obturation.

bubbles serve to desirably increase the temperature and further generate significant pressure on an intracanal irrigant, which in a small, microscopic space serves to promote surface cleaning. Additional studies have shown that fluid hydrodynamics is the only mechanism to clean root canal surfaces and systems.[11,14]

Gulabivala has shown that fluid agitation removes simulated biofilms in extracted teeth. Further, he has shown that hydrodynamics is a function of the canal shape, the size of the activator tip selected, the activation time, the volume of irrigant, the motion of the activator, and the temperature of the irrigant.[45] Lambrechts' team states that fluid activation in conjunction with PAD is an absolute must-have to maximize 3-dimensional cleaning.[11] Following root canal preparation procedures, the clinical protocol is to use the EndoActivator to agitate an intracanal solution of full strength NaOCl for 60 seconds. Agitating an intracanal reagent serves to move debris into solution. As such, voluminous irrigation and intracanal suction should be performed to remove this loose debris.[36] This process should be repeated for each intracanal irrigant used or until the fluid in the pulp chamber is observed to be clean. Following the use of NaOCl, irrigate with a 17% solution of EDTA, and again the EndoActivator may be used to agitate this intracanal solution for 30 seconds. Logically, better cleaning improves the potential for 3-dimensional obturation and long-term success (Figures 15a and 15b).

The Future

These are exciting and turbulent times in clinical endodontics. In the future, successfully treated teeth will be attributable to complete endodontics, whereas failing teeth will be universally understood to be due to deficiencies in primary treatment. One of the more significant advances in the years immediately ahead will be the development of specific methods that will promote 3-dimensional cleaning. Innovative technologies will continue to emerge that will move the field of endodontics ever closer toward achieving the biological goal of complete debridement and disinfection.

When our profession recognizes the importance of treating the entire root canal system, then we will be liberated from this last great controversy, and endodontics will be fun.

Disclosure: Dr. Ruddle has a financial interest in products he designs and develops, which include the ProTaper System.

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