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A new year brings new opportunities

The amount of information available in the dental field about new products, techniques and research data is astounding. Running a practice and seeing patients leaves little time for catching up on the latest clinical news and product information. Thus, I hope roots will not only be a welcome respite for those rare chunks of time you can devote to leisurely reading, but one that provides a practical return on your investment by giving you information that you can actually put to immediate use.

This issue of roots features a collection of articles from some of the most respected names in endodontics. These expert clinicians are sharing their knowledge and expertise with you.

Within this issue, Dr. Gregori M. Kurtzman describes positive versus negative pressure irrigation; Dr. L. Stephen Buchanan writes about negotiating and shaping around anatomic impediments; and Dr. Barry Lee Musikant shares his perspective on “the rules of engagement.” In addition, Dr. Enrico DiVito, Prof. Rolando Crippa, Prof. Giuseppe Iaria, Prof. Vasilios Kaitzas, Prof. Stefano Benedicenti and Prof. Giovanni Olivi share the latest information on the use of lasers in endodontics.

But there’s more.

Every issue of roots also contains a C.E. component. By reading the article on the antibacterial effects of lasers in endodontics by Dr. Selma Cristina Cury Camargo, then taking a short online quiz about this article at www.DTStudyClub.com, you will gain one ADA CERP-certified C.E. credit. Keep in mind that since roots is a quarterly magazine, you can actually chisel four C.E. credits per year out of your already busy life without the lost revenue and time away from your practice.

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I know that taking time away from your practice to pursue C.E. credits is costly in terms of lost revenue and time, and that is another reason roots is such a valuable publication. I hope you enjoy this issue and that you get the most out of it.

And, for those who will be attending the AAE Annual Session in Boston this spring, please say hello to me there.

Sincerely,

Fred Weinstein, DMD, MRCD(C), FICD
Editor in Chief
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The antibacterial effects of lasers in endodontics

Author_Selma Cristina Cury Camargo, DDS, PhD

**Endodontic infection**

The success of endodontic treatment reaches values between 85 to 97 percent. Adequate treatment protocols, knowledge and infection control are the basic components to achieve such values (Fig. 1). It is well known that apical periodontitis is caused by the communication of root-canal microorganisms and their byproducts with the surrounding periodontal structures. Exposure of dental pulp directly to the oral cavity, or via accessory canals, open dentinal tubules or periodontal pockets, are the most probable routes of the endodontic infection.

Clinically, apical periodontitis is not evident as long as the necrotic tissue is not infected with microorganisms. There are up to 40 isolated species of bacteria present in the root canal. Cocci, rods, filaments, spirochetes, anaerobic and facultative anaerobic are frequently identified in primary infection, fungus can also be isolated.

---

**Fig. 1.** Success in endodontic treatment: apical radiolucency repair.
Endodontic microbiota can be found suspended in the main root canal, adhered to the canal walls and deep in the dentinal tubules at a depth of up to 300 µm (Fig. 2). The absence of cementum dramatically increases bacteria penetration into dentinal tubules.8–11

It has been shown that bacteria can also be found outside the root-canal system, located at the apical cementum and as an external biofilm on the apex.12–15 Following conventional endodontic treatment, 15 to 20 percent of non-vital teeth with apical periodontitis fail.16–18

The presence of bacteria after the decontamination phase or the inability to seal root canal after treatment are reasons for failure.2 The remaining contamination in endodontically treated teeth is able to maintain the infectious disease process in the periapical tissue.

Retreatments are the first choice in failed root canals. The microbiota found in persistent infections differs from that in primary infection (Fig. 3). Facultative anaerobic gram positive (G+) and negative (G-) microorganisms and fungus are easily found.19–21 Special attention is given to Enterococcus faecalis, a resistant facultative anaerobic G+ cocci, identified in a much higher incidence in failed root canals.22–25

The importance of bacterial control plays a significant role in endodontic success. Adequate and effective disinfection of the root-canal system is necessary. Based on that, all efforts must be done in order to achieve this result.

_Endodontic therapy_

The bacterial flora of the root canal must be actively eliminated by a combination of debridement and antimicrobial chemical treatment. Mechanical instrumentation eliminates more than 90 percent of the microbial amount.26

An important point of note is the adequate shaping of the root canal. Evaluating the antibacterial efficacy of mechanical preparation itself, Dalton et al.27 concluded that instrumentation to an apical size of #25 resulted in 20 percent of canals free of cultivable bacteria, when a #35 size was made, 60 percent showed negative results.

Irrigant solution has been associated with mechanical instrumentation to facilitate an instrument’s cutting efficiency, remove debris and the smear layer, dissolve organic matter, clean inaccessible areas and act against microorganisms. Sodium hypochlorite is the most common irrigant used in endodontics.28 It has an excellent cleansing ability, dissolves necrotic tissue, has a potential antibacterial effect and, depending on the concentration, is well tolerated by biological tissues. When added to mechanical instrumentation, it reduces the number of infected canals by 40 to 50 percent.

Other irrigant solutions are also used during endodontic preparation. EDTA, a chelating agent used primarily to remove the smear layer and facilitate the removal of debris from the canal has no antibacterial effect.29 Chlorhexidine gluconate has a strong antibacterial activity to an extensive number of bacteria species, even the resistant Enterococcus faecalis, but it does not break down proteins and necrotic tissue as sodium hypochlorite does.30
Because the association of mechanical instrumentation and irrigant solutions are not able to totally eliminate bacteria from the canal system — a status that is required for root-canal filling — additional substances and medications have been tested in order to suppress the gap that occurs in standard endodontic protocols.

The principal goal of dressing the root canal between appointments is to ensure safe antibacterial action with a long-lasting effect. A great number of medicaments have been used as dressing material, such as formocresol, camphorated parachlorophenol, eugenol, iodine-potassium iodide, antibiotics, calcium hydroxide and chlorhexidine.

Calcium hydroxide has been used in endodontic therapy since 1920. With a high pH at saturation over pH 11, it induces mineralization, reduces bacteria and dissolves tissue. For extended antibacterial effectiveness, the pH must be kept high in the canal and in the dentin as well. This ability depends on the diffusion through dentin tubules.

Although most microorganisms are destroyed at pH 9.5, a few can survive over pH 11 or higher, such as *E. faecalis* and *candida*. Because of the resistance of some microorganisms to conventional treatment protocols — and the direct relation between the presence of viable bacteria in the canal system and the reduced percentage of treatment success — additional effort has to be made to control canal system infection.

**Lasers in endodontics**

Lasers were introduced in endodontics as a complementary step to increase antibacterial efforts in conventional treatments. The antibacterial action of Nd:YAG, diodes, Er:YAG and photo activated disinfection (PAD) have been explored by a number of investigators. In the following section, each laser is evaluated with the aim of selecting an adequate protocol that will result in a high probability of success in teeth with apical periodontitis.

**Nd:YAG laser**

The Nd:YAG laser was one of the first lasers tested in endodontics. It is a solid-state laser. The active medium is usually YAG - yitrum aluminin grenade (Y2AL5O12) where some Y3+ are substituted for Nd3+. It is a four-level energy system operating in a continuous or pulsed mode. It emits a 1064 nm infrared wavelength. Thus, this laser needs a guide light for clinical application. Flexible fibers with a diameter between 200 mm and 400 µm are used as delivery systems. It can be used intracanal, in contact mode (Fig. 4).

Because the association of mechanical instrumentation and irrigant solutions are not able to totally eliminate bacteria from the canal system — a status that is required for root-canal filling — additional substances and medications have been tested in order to suppress the gap that occurs in standard endodontic protocols.
permeability significantly.\textsuperscript{35,36} However, because the emission of the laser beam from the optical fiber is directed along the root canal, not laterally, not all root canal walls are irradiated, which gives more effective action at the apical areas of the root.\textsuperscript{37} Undesirable morphologic changes such as carbonization and cracks are seen only if high parameters of energy are used.

One of the major problems for intra-canal laser irradiation is the increase of temperature at the external surface of the root. When laser light reaches a tissue, a thermal effect occurs. The heat is directly associated to energy used, time and irradiation mode. An increase in temperature levels more than 10 degrees Celsius per one minute can cause damage to periodontal tissues, such as necrosis and anquilose.

Lan (1999)\textsuperscript{38} evaluated in vitro, the temperature increase on the external surface of the root after irradiation with a Nd:YAG laser under the following parameters of energy: 50 mJ, 80 mJ and 100 mJ at 10, 20 and 30 pulses per second. The increase of temperature was less than 10 degrees. The same results were obtained from Bachman et al. (2000)\textsuperscript{39}, Kimura et al. (1999)\textsuperscript{40}, Gutknecht et al. (2008).\textsuperscript{41}

In contrast to the external surface, intra-canal temperature rises dramatically at the apical area, promoting an effective action against bacteria contamination. For the Nd:YAG laser, 1.5 watts and 15 Hz are safe parameters of energy for temperature and morphological changes.\textsuperscript{33,41}

The primary use of the Nd:YAG laser in endodontics is focused on elimination of microorganisms in the root canal system. Rooney et al. (1994)\textsuperscript{42} evaluated the antibacterial effect of Nd:YAG lasers in vitro. Bacterial reduction was obtained considering energy parameters.

Researchers developed different in vitro models simulating the organisms expected in non-vital, contaminated teeth. Nd:YAG irradiation was effective for \textit{Baccilus stearothermophilus}\textsuperscript{43,44}, \textit{Streptococcus faecalis}, \textit{Escherichia coli}\textsuperscript{45}, \textit{Streptococcus mutans}\textsuperscript{46}, \textit{Streptococcus sanguis}, \textit{Prevotella intermedia}\textsuperscript{47} and a specific microorganism resistant to conventional endodontic treatment, \textit{Enterococcus faecalis}.\textsuperscript{48–50} Nd:YAG has an antibacterial effect in dentin at a depth of 1000 µm\textsuperscript{50} (Fig. 5).

Histological models were also developed in order to evaluate periapical tissue response after intra-canal Nd:YAG laser irradiation. Suda et al. (1996)\textsuperscript{51} proved in dog models that Nd:YAG irradiation that 100 mJ/30 pps (pulses per second) during 30 seconds was safe to surrounding root tissues. Maresca et al. (1996)\textsuperscript{52}, using human teeth indicated for apical surgery, confirmed Suda et al.\textsuperscript{51} and Ianamoto et al. (1998)\textsuperscript{53} results. Koba et al. (1999)\textsuperscript{54} analyzed histopathological inflammatory response after Nd:YAG irradiation in dogs using 1 watt and 2 watts. Results showed significant inflammatory reduction in four and eight weeks compared to the non-irradiated group.

Clinical reports published in the literature confirm the benefits of intra-canal Nd:YAG irradiation. In 1993, Eduardo et al.\textsuperscript{55} published a successfully clinical case that associated conventional endodontic treatment with Nd:YAG irradiation for retreatment, apical periodontitis, acute abscess and perforation. Clinical and radiographic follow up showed complete healing after six months.

Similar results were shown by Camargo et al. (1998).\textsuperscript{56} Gutknecht et al. (1996)\textsuperscript{57} reported a significant improvement in healing of laser-treated infected canals, when compared to non-irradiated cases.

Camargo et al. (2002)\textsuperscript{58} compared in vivo the antibacterial effects of conventional endodontic treatment and conventional protocol associated to the Nd:YAG laser. Teeth with apical radiolucency, no symptoms and necrotic pulps were selected and divided into two groups: conventional treatment and laser irradiated.

Microbiological samples were taken before canal instrumentation, after canal preparation and/or laser irradiation and one week after treatment. Results showed a significant antibacterial effect in the laser group compared to the standard protocol. When no other bactericidal agent was used, it is assumed that the Nd:YAG laser played a specific role in bacterial reduction for endodontic treatment in patients.

\section*{Diodes}

The diode laser is a solid-state semiconductor laser that uses a combination of gallium, arsenide,
Lasers in endodontics

Aluminum and/or indium as the active medium. The available wavelength for dental use ranges between 800 and 1064 nm that emits in continuous and gated pulsed mode using an optical fiber as the delivery system (Fig. 6).

Diode lasers have gained increasing importance in dentistry due to their compactness and affordable cost. A combination of smear layer removal, bacterial reduction and less apical leakage brings importance to this system and makes it viable for endodontic treatment. The principal laser action is photothermal.

The thermal effect on tissue depends on the irradiation mode and settings. Wang et al. (2005) irradiated root canals in vitro and demonstrated a maximum temperature increase of 8.1 degrees Celsius using 5 watt for seven seconds. Similar results were obtained by da Costa Ribeiro.60 Gutknecht et al. (2005) evaluated intra-canal diode irradiation with an output set of 1.5 watts observed a temperature increase in the external surface of the root of 7 degrees Celsius with 980 nm of diode irradiation at a power setting of 2.5 watts at a continuous and chopped mode and demonstrated that the temperature increase never exceeded 47 degrees Celsius, which is considered safe for periodontal structures.41

Clean intra-canal dentin surfaces with closed dentinal tubules, indicating melting and recrystallization, were morphological changes observed at the apical portion of the root after intra-canal diode irradiation.62 In general, near infrared wavelengths, such as 1064 nm and 980 nm, promote fusion and recrystallization on the dentin surface, closing dentinal tubules.

The apparent consensus is that diode laser irradiation has a potential antibacterial effect. In most cases, the effect is directly related to the amount of energy delivered.

In a comparative study designed by Gutknecht et al. (1997), an 810 nm diode was able to reduce bacteria contamination up to 88.38 percent with a distal output of 0.6 watts in CW mode.

A 980 nm diode laser has an efficient antibacterial effect in root canals contaminated with Enterococcus faecalis at an average between 77 to 97 percent. Energy outputs of 1.7 watts, 2.3 watts and 2.8 watts were tested. Efficiency was directly related to the amount of energy and dentin thickness.64

Er:YAG laser

Er:YAG lasers are solid-state lasers whose lasing medium is erbium-doped yttrium aluminium garnet (Er:Y3Al5O12). Er:YAG lasers typically
emit light with a wavelength of 2940 nm, which is infrared light. Unlike Nd:YAG lasers, the output of an Er:YAG laser is strongly absorbed by water because of atomic resonances. The Er:YAG wavelength is well absorbed by hard dental tissue. This laser was approved for dental procedures in 1997. Smear layer removal, canal preparation and apicoectomy are the indications for endodontics (Fig. 7).

The morphology of dentinal surface irradiated with an Er:YAG laser is characterized by clean areas showing opened dentinal tubules free of smear layer in a globular surface. The effects on bacterial reduction by Er:YAG was observed by Moritz et al. (1999).65 Stabholz et al. (2003)37 described a new endodontic tip that can be used with an Er:YAG laser system.

The tip allows lateral emission of the radiation rather than direct emission through a single opening at the far end. It emits through a spiral tip located along the length of the tip. In order to examine the efficacy of the spiral tip in removing smear layer, Stabholz et al. (2003)66 showed cleaned intra-canal dentin walls free of smear layer and debris under SEM evaluation.

Photo activated disinfection (PAD)

Another method of disinfection in endodontics is also available. Photo activated disinfection (PAD) is based on the principle that photo-activatable substances that bind to the target cells and are activated by light of suitable wavelength. Free radicals are formed, producing a toxic effect to bacteria. Toluidine blue and methylene blue are examples of photo-activatable substances.

Tolonium chloride is able to kill most of the existing bacteria. In vitro studies, PAD has an effective action against photosensitive bacteria such as E. faecalis, Fusobacterium nucleatum, Prevotella intermedia, Peptostreptococcus micros and Actinomycetemcomitans.67,68

On the other hand, Souza et al. (2010)69, evaluating PAD antibacterial effects as a supplement to instrumentation / irrigation in infected canals with E faecalis, did not prove significant effect regards to intra-canal disinfection. Further adjustments in the PAD protocols and comparative research models may be required to before clinical usage recommendations.

Discussion and conclusion

There are good reasons to focus the treatment of non-vital contaminated teeth upon the destruction of bacteria in the root canal. The chances for a favorable outcome of the treatment are significantly higher if the canal is free from bacteria when it is obturated.

If, on the other hand, bacteria persist at the time of root filling, there is a higher risk of failure treatment. Therefore, the prime objective of treatment is to achieve the complete elimination of all bacteria from the root canal system.2,31

Today, the potential antibacterial effect of laser irradiation associated with the bio-stimulation action and accelerated healing process is well known. Research has supported the improvement of endodontic protocol.

![Fig. 8_Endodontic laser therapeutic plan.](image8.png)

![Fig. 9_Intra-canal laser irradiation, molars.](image9.png)
An endodontic laser therapeutic plan brings benefits to conventional treatment, such as minimal apical leakage, effective action against resistant microorganisms and on external apical biofilm, and an increase in periapical tissue repair. Based on that, laser procedures have been incorporated into conventional therapeutic concepts to improve endodontic therapy (Fig. 8).

Clinical studies have shown the benefits of an endo-laser protocol in apical periodontitis treatment. For endodontic treatment, laser protocol is a combination of standard treatment strategies associating cleaning and shaping the root canal with a minimal adequate shape up to #35, irrigant solutions with antibacterial properties and intra-canal laser irradiation using controlled parameters of energy. Ideal sealing of the root canal and adequate coronal restoration are needed for an optimal result.

In practice, little additional time is required for laser treatment. Irradiation technique is simple once flexible optical fibers of 200 µm in diameter are used. The fiber can easily reach the apical third of the root canal, even in curved molars (Fig. 9). The released laser energy has an effect in dentin layers and beyond the apex in the periapical region. The laser’s effect is applicable in inaccessible areas, such as external biofilm adhered at the root apex.

Irradiation technique must follow basic principles. A humid root canal is required and rotary movements from the coronal portion to the apex should be carried out, as well as scanning the root canal walls in contact mode (Fig. 10). The power settings and irradiation mode depend on one’s choice of a specific wavelength.

Nd:YAG, diodes in different wavelength emissions, Er:YAG, Er:Cr:YSGG and low-power lasers can be used for different procedures with acceptable results. Laser technology in dentistry is a reality. The development of specific delivery systems and the evolution of lasers combined with a better understanding of laser–tissue interaction increase the opportunities and indications in the endodontic field.

Editorial note: This article was first published in the international edition of Laser, issue 2/2011. A list of references is available from the publisher.

About the author

Selma Camargo, DDS, PhD, received a doctorate in endodontics, a specialist and master’s degree and a laser in dentistry unit from the University of Cidade de São Paulo, Brazil. She is a professor of endodontics and general dentistry at the University of Cidade de São Paulo, Brazil. She conducted research in endodontics (master’s) at the University of British Columbia, Vancouver, Canada; and research in endodontics (PhD) at University of Oslo, Norway. She may be contacted at University of Cidade de São Paulo, Brazil, Rua Pinto Gonçalves, 85/54 Perdizes, São Paulo, SP Brazil 05005-010, selmacris@me.com.
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Positive versus negative pressure irrigation

Author_Gregori M. Kurtzman, DDS, MAGD, FACD, FPFA, FADI, DICOI, DADIA

_The endodontic triad_

Long-term endodontic success is not due to a single factor but is dependent upon three critical aspects of treatment called the “endodontic triad” — instrumentation, disinfection and obturation. These three components of the triad are interwoven, and success requires careful attention to all three to provide long term-clinical success.

Teeth have very complex pulpal anatomy, and instrumentation alone cannot adequately prepare the canal system for obturation. The intricacies of the canal anatomy with its fins, lateral canals and apical deltas make it impossible for endodontic instruments to reach all aspects of the anatomy (Fig. 1). Thus irrigation is critical for removal of residual tissue and microbiota that cannot be reached by instrumentation of the main canals.

Regardless of the file system used for instrumentation, files cannot reach all of the pulpal anatomy, and therefore disinfection is key to augmenting the cleaning process prior to obturation. But what is referred to when we mention disinfection of the canal system? Disinfection comprises removal of the residual tissue in the canal system and the associated bacteria through flushing the canal system with irrigating solution. The key being to remove as much residual tissue as possible and the more thorough the irrigation process the lower the remaining bacterial level. The less residual tissue remaining the less bacteria and the more successful the clinical outcome of the endodontic treatment.

_Cleaning the canal_

No matter what obturation material is used, how well the sealer adheres to the canal walls is important. Smear layer can play a factor that may prevent sealer penetration into the dentinal tubules. The frequency of bacterial penetration through teeth obturated with intact smear layer (70 percent) was significantly greater than that of teeth from which the smear layer had been removed (30 percent). Removal of the smear layer enhanced sealability as evidenced by increased resistance to bacterial penetration.¹ The incidence of apical leakage was reduced in the absence of the smear, and the adaptation of gutta-percha was improved no matter what obturation method was used later.²,³,⁴

What is used to obturate the canals is important; however, the manner in which the canal was

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Fig. 1. Cleared molar with dye within the canal system illustrating the complex anatomy normally found in teeth. (Photos/Provided by Dr. Gregori M. Kurtzman)
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Prepared prior to obturation also determines how well the canal is sealed. Rotary instrumentation with NiTi files has shown less microleakage than hand-instrumented canals irrespective of what was used to obturate the canal. The machining of the canal walls with NiTi rotary instruments provides smoother canal walls and shapes that are easier to obturate when compared to stainless steel hand filing. The better the adaptation of the obturation material to the instrumented dentinal walls, the less leakage is to be expected along the entire root length. The better the canal walls are prepared and cleaned, the more smear layer and organic debris is removed which is beneficial to root canal sealing.

Smear layer removal is best achieved by irrigating the canals with NaOCl (sodium hypochlorite) followed by 17 percent EDTA solution. NaOCl dissolves the organic component of the smear layer exposing the dentinal tubules lining the canal walls, whereas EDTA, a chelating agent, dissolves the inorganic portion of the dentin opening the dentinal tubules. Alternating between the two irrigants as the instrumentation is being performed will permit removal of more organic debris further into the tubules, increasing resistance to bacterial penetration once the canal is obturated.

Studies suggest that regular exchange and the use of large amounts of irrigant should maintain the antibacterial effectiveness of the NaOCl solution, compensating for the effects of concentration. Volume is more critical to canal disinfection during treatment than the concentration of the irrigant. Flushing of the irrigant also serves to remove the debris exposing the dentin around the anatomy in the canal system to further action of the irrigant improving the efficacy of the process.

**Positive vs. negative pressure**

Irrigation as it relates to endodontic treatment involves placement of an irrigating solution into the canal system and its evacuation from the tooth. Traditionally, this involved placement of the irrigant with an end-port or side-port needle into the apical canal and expressing solution out of the needle to be suctioned coronally. This creates a positive pressure system with force created at the end of the needle, which may lead to solution being forced into the periapical tissues. Positive pressure irrigation has its risks as some irrigating solutions, such as sodium hypochlorite, have the potential to cause tissue injury that may be extensive when encountering the periapical tissue and its communication with tissue spaces (Fig. 2). These NaOCl accidents can lead to permanent physical injury or disability with facial deformation and neurological complications.

Chow was able to show as early as 1983, that positive pressure irrigation has little or no effect apical to the needles orifice. This is highlighted in his paradigm on endodontic irrigation, “For the solution to be mechanically effective in removing all the particles, it has to: (a) reach the apex, (b) create a current force and (c) carry the particles away.” We increase the risk of clinical failure due to the inability to eliminate intraradicular microorganisms from the canal system, especially in the apical portion of the root.

A negative pressure irrigation system on the other hand does not create positive pressure force at the needle’s tip, so potential accidents are essentially eliminated. In a negative pressure irrigation system, the irrigation solution is expressed coronally, and suction at the tip of the irrigation needle at the apex creates a current flow down the canal towards the apex and is drawn up the needle. But true apical negative pressure only occurs when the needle (cannula) is utilized to aspirate irrigants from the apical termination of the root canal. The apical suction pulls irrigating solution down the canal walls toward the apex, creating a rapid turbulent current force towards the terminus of the needle (Fig. 3). Haas and Edson found, “The teeth irrigated with negative apical pressure had no apical leakage. While the teeth irrigated with positive pressure leaked an average of 2.41 mL out of 3 mL.” A study by Fukumoto found using negative pressure there was less extrusion of irrigant than when using needle irrigation (positive pressure) when both were placed 2 mm from working length.

But what other sequela can occur with minute amounts of NaOCl leaking from the apex during the irrigation process? Gondim et al, in a study of post-operative pain when comparing positive a negative...
pressure irrigation systems reported, “The outcome of this investigation indicates that the use of a negative pressure irrigation device can result in a significant reduction in postoperative pain levels in comparison to conventional needle irrigation.”17 So although we may not see NaOCL accidents frequently, it is possible to see the effects of positive pressure irrigation allowing some minute extrusion apically in our normal, day-to-day endodontic treatment. They further stated that “the use of the EndoVac system did not result in apical extrusion of irrigant, hence chemical irritation of the periapical tissues leading to postoperative pain may not be likely.” And they concluded, “It is safe to use a negative pressure irrigation protocol for antimicrobial debridement up to the full working length.”

_EndoVac endodontic irrigation system

Designed by Dr. G. John Schoeffel with more than a decade of research, the EndoVac irrigation system (SybronEndo, Orange, Calif.) was developed as a means to irrigate and remove debris to the apical constrictures without forcing solution out the apex into the periapical tissue. The system utilizes negative pressure through the office’s high volume evacuation system permitting thorough irrigation with high volumes of irrigation solution.

The EndoVac system consists of Multi-Port Adapter (MPA) assembly that connects to the high volume evacuation hose in the dental operatory (Figs. 4, 5). To this, connects the Master Delivery Tip (irrigation and suction together) with a disposable syringe filled with irrigation solution (Figs. 6, 7). Either a MacroCannula (Fig. 8) or MicroCannula (Fig. 9) is attached and used simultaneously with the Master Delivery Tip during treatment. The plastic MacroCannula is placed on a handpiece that is attached to tubing that connects to the MPA via a separate line. This is used for coarse debris removal. The MicroCannula is a metal suction tip available in either 21, 25 or 31 mm lengths with 12 micro holes in the terminal 0.7 mm of the tip, permitting removal of particles that are 100 microns or smaller to the apical constriction. This tip fits into a metal fingerpiece and is connected to the Multi-Port Adapter (Fig. 5) in the HVE via tubing. The turbulent current forces developed by the MicroCannula rapidly flows to the micro holes at the terminus, which can reach within 0.2 mm of full working length. Quite simply, the vacuum formed at the tip of the MicroCannula is able to achieve each of Chow’s objectives in his irrigation paradigm.
Nielsen and Baumgartner found the volume of irrigant delivered with the EndoVac system was significantly more than the volume delivered with needle irrigation over the same amount of time. Furthermore, they reported significantly better debridement 1 mm from working length for the EndoVac system compared with needle irrigation.

Since one of the laws of physics states, "only one object can occupy a space at a time," if the tissue remnants can be removed from the lateral canals, apical deltas and fins within the canal system, these areas can be filled with obturation material providing a better seal and inhibiting bacteria in or out of the canal system. The EndoVac irrigation system, as Nielsen and Baumgartner demonstrated, is able to better clean at the apex where other irrigation methods and systems have not been able to do as thorough a job (Figs. 10–12).

**EndoVac technique**

Following removal of the chamber roof and exposure of the pulp, the Master Delivery Tip is used to provide frequent and abundant irrigation as the orifices are identified and explored. The Master Delivery Tip may be used to deliver irrigant into the pulp chamber while also suctioning debris brought coronally during the instrumentation process. Be careful to deliver the irrigant passively into the pulp chamber, avoiding delivering irrigant directly into the orifice as this will create positive apical pressure (Fig. 13). The benefit of the Master Delivery Tip is that with a single tip at the tooth’s access, visibility is not blocked and large volumes of irrigation solution can be utilized. As the canals are being instrumented to a size 30 with a 0.04 taper, the MacroCannula is introduced between changes in file size as the canal is shaped. The MacroCannula is utilized to remove coarse debris during instrumentation and is used in combination with the Master Delivery Tip, which delivers the irrigating solution. Negative pressure is created as irrigating solution is drawn down the canal towards the apex as it is expressed from the Master Delivery Tip and then is drawn up the MacroCannula (Fig. 14). It is sug-
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gusted that the MacroCannula be used with a slight pumping motion as each canal is flushed. Irrigation should continue with the MacroCannula until clear fluid is observed being withdrawn through the tubing connected to the handpiece before proceeding to the next file.

When the canal has been enlarged to the desired size, the MacroCannula is again used until clear solution is observed in the tubing. This will ensure that all coarse debris has been removed from the canal. Next, the metal MicroCannula is placed on the Fingerpiece and attached to the MPA connector line (white connection) and used at the completion of canal instrumentation to remove fine debris to the apical constricture under negative pressure when the canal has been instrumented to a size 35 with a 0.04 taper or greater (Fig. 15). To prevent plugging of the fine holes in the apical terminus do not use the MicroCannula until thorough irrigation has been accomplished with the MacroCannula and all instrumentation has been completed.

Conclusion

Instrumentation, disinfection and obturation are important aspects of rendering quality endodontic care. Yet, the instruments we use to prepare the canal, whether hand or mechanized are unable to reach all aspects of the canal system. Irrigation is key to cleaning and disinfecting those areas that cannot be reached by instrumentation alone.

The EndoVac irrigation system with its negative pressure is able to more much larger volumes of irrigant through the canal system, safely, resulting in more thorough removal of the micro debris at the apical constrictive, thereby providing a better environment for sealing. Accordingly, negative pressure irrigation not only greatly improves both the flow and safety of irrigation with NaOCL but has also been shown to minimize postoperative sensitivity following treatment compared to traditional positive pressure irrigation protocols.

A complete list of references is available from the publisher, feedback@dental-tribune.com.

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Perform endodontic therapy on 10 molars and chances are you ran into at least one anatomic impediment. Despite the significant occurrence rate, few of us have been taught how to identify and manage apical impediments, let alone those that occur in the coronal third.

Without a clever technique for these cases, the right instruments and an accurate mental image of the canal space you are in, you have virtually no chance of reaching the end of the root canal space, significantly increasing the chances of persistent apical infection. With the right stuff, managing these endodontic challenges can be a fascinating procedural experience requiring little extra time and delivering remarkably predictable outcomes.

Let’s begin with a look at the different types of impediments (Figs. 1–6):

**Anatomic impediments**

1. Apical irregularity at the terminus of a relatively straight canal.
2. Irregularity on the outside wall of a curved canal.
3. Abruptly curved canal.

**Iatrogenic impediments**

4. Apical blockage
5. Apical ledging
6. Remnant of instrument

How do you know you have met an impediment? That’s easy — by the tactile sensation felt as loose resistance to file advancement. Tight resistance to file advancement is the sensation felt when a file moving apically binds and then exhibits tug-back upon removal. Tight resistance means the file is binding on two opposite sides. Usually in this case, working the file (push-pull, balanced force, rotary, etc.) will allow it to progress apically.

Loose resistance to file advancement means that the file tip is caught either in some type of an irregularity (lateral canal, isthmus, fin) or the file tip is bumping into the outside wall of an acutely curved canal. All that remains in the diagnosis of apical impediment is to apply an apex locator (Fig. 7) lead to the file and confirm a short reading (and obviously an apex locator is the best method of determining when you have actually reached the Holy Grail — length). OK, so how do we deal with the aforementioned impedimento?*

First off, we do not ever attack or even firmly engage an impediment with the tip of any instru-
ment. That’s how ledges happen, and a ledged canal is waaaaaaay more difficult to manage successfully than just a severely curved canal. Aspire to the maxim, “If you can’t fix it, don’t fix it so nobody else can fix it.”

Managing impediments is all about file bending, mental visualization and patient, skilled technique. So let’s discuss file bending.

_When and how to bend negotiating files_

You might be surprised to read that I find it unnecessary to slightly curve all negotiating files before use — a method most of us were taught. Due to their exceptional flexibility, unbent K-files sizes smaller than #15 will easily traverse impediment-free canals with greater than 90-degree curvatures (Fig. 8). Try using only straight negotiating files for a time — assuming you negotiate through a lubricant and start with an 08 K-file in small canals. You will be amazed at how often you get to length without bending them. At the end of the day, using cotton pliers with that ribbon-curling motion on your smallish files is a waste of time, so my advice is to stop yourself. You don’t have to do that anymore. Not doing that could save weeks of your life over a career.

_Mental imaging_

To understand this important concept better, try this thought experiment:

Be the file.

Imagine that you are the negotiating file moving into a canal. You have a subtle curve along your whole length and because you are being used in a watch-winding motion your tip is waving back and forth “scouting” loosely through the canal, and, just as estimated length nears, “dink, dink” — loose resistance to apical advancement (Figs. 9,10) — shoot! We pull back, re-approach, and get the same result regardless of how we manipulate the instrument.

To better understand why this has occurred, ribbon-curl a #10 K-file with cotton pliers along its full length and then clamp the file with a hemostat about 4 mm back from the tip. Look at the tip portion with magnification and you will see an essentially straight instrument tip. And this is the part of the file.

---

**Fig. 1.** Apical irregularity at the terminus of a relatively straight canal. (Photos/Provided by Dr. L. Stephen Buchanan)

**Fig. 2.** Irregularity on the outside wall of a curved canal.

**Fig. 3.** Abruptly curved canal.

**Fig. 4.** Apical blockage.

**Fig. 5.** Apical ledging.

**Fig. 6.** Remnant of instrument.
that is supposed to make its way around a canal path that is radically more bent.

Another way to say it is that the file tip was not bent acutely enough to keep the file tip centered as it moved into the tightly breaking canal curvature. When a file is curved 25 degrees along its whole length, it will never make it around a canal curvature that is 90 degrees along its last 1-2 mm.

_Mentally imaging the canals you are treating, coupled with the use of appropriately curved files, just needs a bit of clever technique to conquer the apical impediment. The first clever technique trick is to pre-bend the last 1-2 mm of the file with an EndoBender (SybronEndo) (Fig. 11), look down the length of the file and carefully adjust the indicator on the stop (notch, line or point) to be in line with the bend of the file.

Now, as you scritch-scratch into the canal, hunting for the path of least resistance, you feel and see the file passively drop deeper into the canal as you advanced in a new direction. Now, after you have successfully snaked the file around this one-of-a-kind, difficult anatomy, the next question is, “How will I get back here with my next instrument?”

All you have to do is to look at the indicator on the stop, note the direction and after bending the next file and aligning the stop to the bend you simply move the file to length with its bent tip pointing in the same direction as the previous file to length.

_Final impedimento negotiating advice

• Remember that there is little forgiveness in a tightly curved canal, so for goodness sake do anything to avoid blocking the end of the canal. Most often, compacted blockage at a canal curvature will never allow re-entry along the original canal path so despite a lot of effort spent attempting to regain patency, the most likely outcome will be apical perforation with these small instruments.
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• Use an apex locator or you are working waaay too hard without a clue as to where you are. Is that acceptable to you when you could spend less time and definitively nail length with an apex locator.
• Never initially thread the apical half of a small canal with larger than a #08 K-file. Never negotiate any canals without a lubricant in the access cavity.
• Once you battle your way to length with that tiny first instrument, don’t just get patent a mm out the end of the canal — in this case I suggest you go 3-4 mm long and do 30-40 push-pull filing strokes to loosen the file and slightly enlarge the canal. This act will greatly improve your chances of avoiding blockage with the next largest file. There are few experiences more frustrating than to have cleverly and heroically battled your way to length through a hideously tortuous root canal, never to return again.
• Distal canals of lower molars and DB canals in upper molars commonly have severely, abruptly curving canals enclosed inside remarkably straight external root structure. Look for loose resistance to apical advancement, when you feel it whip that instrument out, bend the very tip just short of 90 degrees, adjust the stop indicator, and go hunting!

So now, if you have managed to sneak to length and establish a file path around the impediment, it is left to shape to and beyond the impediment in preparation for cleaning and obturation.

_Shaping around impediments

Let’s begin with a discussion about shaping objectives. The objective of every known endodontic preparation method is to enlarge the canal (by some amount) short of the end of the primary root canal terminus. First, to debride the canal of inflamed, infectious goop, and second, to create resistance form near the very end of the canal to allow obturating materials to be more densely packed and tightly sealed.

The narrowest part of a prepared canal should be at its end.

Unless we are able to successfully shape around an impediment, there will be a discontinuity of taper at that point — so the narrow part next to the impediment has gotta go.

Let’s start by doing the #10 file test. Measure a brand-new #10 SS K-file to the negotiated length and insert it, unbent, into the canal. See if it will go to and through the end of the canal. If it does, the impediment has been reduced just by the canal-smoothing action of the small negotiating files. In this case, carry on as if the impediment never happened and finish the shape. If the #10 file meets loose resistance to apical file placement, simply shorten the stop to the reference point, measure the file, and you now know the length to impediment.

Measure the first rotary shaping file 1 mm short of the length to impediment — this will ensure that the impediment is not engaged and dinged inadvertently — and cut to that length.

_Coronal shape

In small canals, I begin shaping with a 20-.06 GTX file and in larger canals I begin with a 30-.08 GTX. As impediments are located some distance short of terminal length, in a wider part of the canal, these initial instruments usually cut to the prescribed length 1 mm short of the impediment. If the canal will accept it, I then cut the next tip size up — in small canals to a 30-.06 and in larger canals a 40-.08 — 1-2 mm shy of impedimento-town.

_Apical shape

With this larger coronal shape developed (but limited to 1mm by GTX files), it will be much easier to skate pre-bent SS K-files beyond the impediment and to their intended final position. The strategy for this next piece is basically to cut an apical taper using a serial step-back method with SS K-file sizes #10, 15, 20, 25, 30, 35, 40 in multiple recapitulations:

10, 15, 20, 25, 30, then;
15, 20, 25, 30, 35, then;
20, 25, 30, 35, 40 in small canals, or;
25, 30, 35, 40 in larger canals.

The trick here is to keep it loose, avoid engaging the impediment and move every file in the series to their...
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<td>?</td>
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<td>DISSOLVES(^4) necrotic pulp</td>
<td>✔ YES</td>
<td>NO</td>
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<td>REMOVES ALL ORGANIC(^5) components of the smear layer</td>
<td>✔ YES</td>
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<td>REMOVES ALL INORGANIC(^6) components of the smear layer</td>
<td>✔ YES</td>
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<tr>
<td>KILLS BACTERIA(^7) in the presence of smear layer</td>
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dynamic, binding points beyond the impediment, do a short amplitude watch-winding motion to cut a bit, and then place the next file in the series. Any time you wonder to yourself whether you should irrigate, you should irrigate. If this question never occurs to you, you need to review your clinical RCT objectives and think about it more often.

**Shaping past the impediment**

So we have shape coronal to the impediment and a nice apical preparation just beyond the impediment, so in this case the discontinuity of taper we must resolve is at the impediment, rather than at the end of the canal.

To finish the preparation, there is no faster nor surer way to get this done than to bend the tip of a rotary file, sneak it by hand around the impediment, click the SS handpiece onto the latch-grip handle, and spin it to length or beyond. I know, it gave me the willies the first time I did it, but it works like a champ. Obviously use a new file and remember that bending a shape memory rotary file requires a bending plier as used above, and after grasping the instrument tip, over-bend it to about 180 degrees. When released, the file tip will retain a 35-to 45-degree bend — enough to bypass the impediment after coronal and apical shaping.

Irrigation with 6 percent NaOCl and 17 percent EDTA must follow. If you can apply irrigants for a long enough time frame (vital-40 minutes, necrotic-20 minutes) at that appointment, fill it at that appointment. If not, place CaOH in the shaped canals for two weeks, irrigate half the above time, and fill.

**Conclusions**

Blocking, ledging or just never getting to the terminus because of a mishandled impediment is not the end of the world, but it’s not the end of the canal either.

Gone are those halcyon days when we could get away with telling curious patients that blocked canals were calcified apically. Never mind, apply these principles (Figs. 12,13) and I’ll see you at the apex!*

*Italian for impediment

**Fig. 12** Prebent file to length beyond the impediment and around 160 degrees of curvature.

**Fig. 13** Post-operative X-ray showing three portals of exit in the distal root.

**about the author**

L. Stephen Buchanan, DDS, FICO, FACD, was valedictorian of his class at the University of the Pacific School of Dentistry, and he completed the endodontic graduate program at Temple University in Philadelphia in 1980. He began pursuing 3-D anatomy research early in his career, and in 1986 he became the first person in dentistry to use micro CT technology to show the intricacies of root structure. In 1989 he established Dental Education Laboratories, through which he has lectured and conducted participation courses around the world. Buchanan holds a number of patents for dental instruments and techniques, including variably tapered shaping instruments for use in endodontics. He pioneered a system-based approach to treating root canals. He is a diplomate of the American Board of Endodontics. He maintains a private practice limited to endodontics and implant surgery in Santa Barbara, Calif. Contact him at 1515 State St., Suite 16, Santa Barbara, Calif. 93101, (800) 528-1590 or (805) 899-4529, info@endobuchanan.com, www.endobuchanan.com.
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PATENT PENDING
We have heard the term “rules of engagement” used in the military to categorize a line of behavior that best fits the various situations that may arise. These rules are a product of experience, war college exercises and think tanks. They are critical because war is not a game and what starts off as an orderly process can rapidly degenerate in the fog of war.

While not as all-consuming as war, we need rules of engagement in endodontics. The American Association of Endodontists has established guidelines for determining degrees of case difficulty, implying beyond a certain degree of complexity, the cases should be referred to a specialist. While case assessment is a worthy goal, it is unrealistic to determine when a case should actually be sent to a specialist because of the wide range of endodontic skills that individual dentists bring to the tasks.

Rather than impose generalized rules, I think it is more productive to apply rules of engagement on the basis of sound mechanical principles, principles that apply to both the design and implementation of the instruments designated for endodontic procedures. Once dentists understand basic mechanical principles, it will become readily apparent what anatomical situations will impose greater burdens on the instruments and the dentists employing them. I don’t completely agree with an opinion that I have read in various venues stating that it is not the instrument, but the dentist employing it that matters. In fact, there is a continuous interaction between any instrument and the dentist using it and a well-designed instrument used in the most efficacious manner can reduce the challenges when encountering complex anatomy.

The best way to utilize the rules of engagement is to apply the logic that support these rules, one rule at a time and then observe how they interact with other rules having a neutral, positive or negative effect on the overall procedure. Let’s start with initial canal access. The goal is to gain access to the entire canal system while minimizing the amount of tooth structure that we must remove.

The more calcified the case, the greater the amount of overlying secondary dentin obscuring our access to the canal orifices. To discover these canals, we are most likely going to have to go deeper and wider since canals diverge from the chamber as they travel apically. Calcified chambers represent a line of division for some dentists who may then decide to refer out. For them, they have confronted the first rule of engagement, namely encountering a situation where they are uncomfortable in proceeding, and have correctly decided to withdraw. I say correctly because deferring to those with greater skills and experience is never a bad decision, although this is not what this article is about.
Typically, dentists will use either a No. 4 or 6 round bur to gain access into the pulp chamber and then straighten the walls with either barrel-type diamonds or carbide burs. Whether or not the canals are calcified the pulp chamber is approximately 7 mm apical to the cusp tip unless the cusp tip has been severely worn down (Fig. 1). Having a clearly defined 7 mm mark along the length of a surgical length high-speed bur makes aligning the appropriate depth easier (Fig. 2). With the roof completely removed either by pulling up with the round bur or the use of the barrel diamonds or stainless-steel carbide burs, we may be staring at a floor that gives little hint that it was once occupied by a soft gelatinous pulp tissue. What takes its place are pulp stones that grow from the floor coronally, are often somewhat translucent and take on a yellowish tint. At times these stones may actually cleave off the floor and walls of the canal while at other times they hold on quite tenaciously and must be removed with drills or ultrasonics.

Because these stones grow coronally from the floor, their presence is often denoted by a groove between the walls and the centrally placed stone (Fig. 3). The best place to concentrate on removing the stones while searching for canal orifices is along these grooves. I prefer the use of drills to explore the depth of these grooves rather than ultrasonics. Drills leave a smooth floor, while ultrasonics leave the floors scoured. It is easier to find any tissue inclusions when they represent interruptions in an otherwise smooth floor (Fig. 4). For the past several years I have been using Munce burs (CJM Engineering) that are a series of round burs from 0.25 to 4 on 34 mm shafts (Fig 5). Recently, I have been experimenting with EndoGuide burs (SS White) (Figs. 6a, 6b) that for the most part are triangular in shape with rounded tips sizes that are smaller than Munce burs. Both readily cut the dentin in a very controlled fashion. I believe the EndoGuide burs are able to trough the grooves somewhat easier because of their triangular design. Working under a microscope using either one of these micro-bur systems gives the dentist the ability to find not only the main canals, but also mb2s, middle mesials and any other aberrant canals that may be present. The depth of the groove represents the limit on how deep you explore. Once a smooth floor is encountered, we now will only go deeper where tissue inclusion bodies appear.

We could say that the rules for further engagement when encountering highly calcified canals would include the need of a microscope or at least fairly powerful loupes with illumination as well as some form of Munce bur or EndoGuide bur. Without these extra tools, referring out becomes a time honored and wise decision.

Once the canals are recognized, we want to confirm their presence by being able to negotiate an instrument through them to the apex. It is quite logical that some of the calcifications encountered in the chamber will also have affected the patency of the canal. When first negotiating through a canal orifice, it is helpful to make sure the chamber is well lubricated with either NaOCl or aqueous EDTA. If vital tissue is present I prefer the use of aqueous EDTA first, because unlike NaOCl it will not congeal the tissue prior to digesting it, making it easier to negotiate through the length of the canal. When resistance is encountered with the first instrument attempting to negotiate into the canal orifice, there are those who suggest the use of stiffer files that can press heavily into what is believed to be the canal opening. I would suggest an opposite approach only using the most flexible reamers that have minimal engagement along length to first attempt to enter into a tight canal. I am against stiff instruments because if you are wrong in your estimate of where patency resides, a stiff instrument is far more likely to produce an indentation into the dentin making it more difficult.
to find the canal. It’s far better to use an instrument with minimal engagement that will find the smallest patent entry into the canal. If such an instrument does not find a patent pathway, it is likely one is still not present at the depth so far attained, and deeper probing with either the Munce burs or the EndoGuide burs is required.

Eventually, the dentist will reach a point where patency exists and he will find it earlier with an 06 reamer than he will with a K-file of the same tip size. By staying within the grooves that were troughed particularly at the apices of what may be a triangular, square or rhomboid floor of the chamber, the dentist is unlikely to perforate through the floor. There are ample landmarks available, and as long as we remain closely attached to them we are unlikely to perforate either through the floor or laterally.

An additional rule of engagement is to use reamers as well as relieved reamers, as I will soon show. Reamers both unrelieved and relieved are compatible in design and utilization with attaining the results you want. First you want to negotiate through the length of the canal as efficiently as possible. K-files, like every true file, have a high number of horizontally oriented flutes on a shaft that is watch-wound into the canal. In the process of applying a horizontal motion (that is what watch winding is) to horizontally oriented flutes, the flutes will engage and disengage without shaving dentin away from the length of the canal walls until the pull stroke is employed. Because watch winding is the predominant motion, it is all wasted energy that does not make for efficient shaping. The pull stroke will shave dentin away from the canal walls, but an instrument designed to shave dentin from the canal walls only on the pull stroke will distort curved canals to the outer wall as the tip size of the instruments increase. On the in-stroke, these same instruments will tend to impact debris apically with a resultant loss of length and further distortions when an attempt is made to regain that length.

Using reamers (SafeSiders, Essential Dental Systems), both unrelieved and relieved, eliminates the problems of K-files, even though they are used in the same exact manner. Reamers, unlike K-files, have flutes that are vertically oriented, immediately shaving dentin away rather than unproductively engaging it (Figs. 7, 8). The best analogy I can think of is a comparison to shaving one’s face with a razor. Please note that effectiveness of the blades on a razor is a result of their orientation being at right angles to the plane of motion. That is why it is on an X. Relieved reamers are more flexible, less engaging and more efficient at shaving dentin away from the canal walls, giving the dentist a superior tactile perception of what the tip of the instrument is encountering.

Superior tactile perception gives the dentist the ability to differentiate between the tip of the instrument hitting a wall or being in a tight canal. The former situation produces no tugback, while the latter produces immediate tugback. If no tugback exists, the dentist removes the instrument, pre-bends it at the tip and manually attempts to negotiate around the impediment. If tugback exists, the dentist uses a twist and pull motion to negotiate to the apex. It is far more difficult to achieve these efficiencies with K-files. Their design is not consistent with the

Fig. 5 Photograph of a Munce Bur.

Figs. 6a, 6b Photograph of SS White EG5 and EG7 burs.
function demanded of them while the reamers both unrelieved and relieved are. All it takes is to try them to confirm these differences.

Let’s expand our rules of engagement. Now let us include the use of reamers as our initial instruments particularly when the canals are most calcified and tortuous in their pathway. Of course, if they are so much more effective in the most difficult situations, why would they not be used in all situations? They should be.

Today’s paradigm is to create a glide path using K-files to a 20 and then switch to some rotary NiTi system. We have just discussed a much more productive alternative to K-files. Rotary instruments may now be used, but I believe we are all aware that the introduction of rotary NiTi does not come without a burden, acceptable to many and not to others. As you may have already surmised, I am referring to the potential for instrument separation, a result of the torsional stress and cyclic fatigue that is intimately associated with rotary NiTi. The NiTi instruments are shaped just like reamers with the exclusion of the flat. They are correctly designed in that regard, but rotation is not the way they should be used. Far better to use reamer designed instruments in a reciprocating handpiece, producing a small arc of motion that severely limits the amount of torsional stress and cyclic fatigue generated. In fact, that is precisely the way we use the relieved reamers, in a reciprocating handpiece (when not used manually with a tight watch-winding stroke) confined to a 30-degree arc of motion. Because the arc of motion is confined, we are not limited in its oscillating speed. Unlike rotary NiTi that is generally used at 150-300 rpm, the reciprocating handpiece operates between 3,000 and 4,000 cycles per minute (Fig. 8).

What the dentist experiences at this frequency is an instrument that literally negotiates through the length of the canal often like a hot knife through butter. While this is certainly a welcome condition, perhaps it is more important for the dentist to know immediately when the canal hits an obstruction. This capability tells the dentist exactly when he should stop using the reamer (either manually or engine-driven) remove it from the canal, pre-bend the tip of the instrument, negotiate manually around the obstacle and, once around, reattach the head to the reciprocating handpiece at the newly negotiated length followed by rapid negotiation to the apex. The reamers, both relieved and unrelieved, are the same instruments used both manually and engine-driven, providing a flexibility that neither K-files nor rotary NiTi can duplicate.

The rules of engagement are now expanded to the use of a reciprocating handpiece over a rotary engine. It is safer and more adaptable to complex anatomy. In fact, there must be much truth to the benefits of reciprocation over rotary NiTi when you see major rotary NiTi companies introducing reciprocating systems. Belatedly, they are recognizing the vulnerabilities of rotary NiTi and substituting a safer approach even though they are likely to cannibalize their own sales of rotary NiTi. While they are making progress in the reduction of instrument separation, they are reducing the cost of these instruments by coming up with techniques that shape canals far less adequately than recommended in the literature. A good deal of research has gone into establishing minimum apical preparations of 35.

The manufacturers of these new oscillating systems are essentially telling dentists that an apical preparation of 25 is sufficient and, where major resistance is encountered, an even smaller apical preparation is acceptable. This is technique divorced from research and the increasingly detailed concept of what we know pulpal anatomy to be. How does a preparation to 25 conical throughout its length comport with anatomy that we know is often highly oval at times in the configuration of sheaths of tissue that are quite thin mesio-distally, but often four to eight times wider bucco-lingually?

Taking this one step further, in those cases where a 25/08 instrument goes to length fairly easily, is it not likely that the ease of negotiation results from a good deal of lateral space within the length of the canal that is not engaging the instrument? If this is the case, is it also not likely that those walls that were not engaged are also not well cleansed? Reciprocating NiTi instruments as they are presently being sold is a solution to a marketing problem that does not
address the requirements for sound biological principles. The rules of engagement tell us that we cannot compromise on canal preparations. They have an immediate impact on irrigation and the obturation that is shortly to follow.

We can round out this discussion by mentioning some recent research that makes all the sense in the world even though we may not have heard about it until recently. Recent research now tells us that the use of rotary NiTi instruments in curved canals results in micro-fractures in the apical third. Micro-fractures in the canals are the mirror image of the micro-fractures in the NiTi instruments that have been reported over the years. The only difference is that while the evolution of NiTi can make it less vulnerable to such micro-fractures, the tooth structure remains the same. Yet another reason for using NiTi in whatever form it is in the most conservative ways, safer for the instruments, but compromised biologic results for the patient.

One last point: Rotary NiTi is noted for the retention of the smear layer particularly in the apical third. This is counterproductive for a well-sealed canal. Reciprocation, on the other hand, has been shown to completely remove the smear layer throughout the length of the canal.

Pictured are some recent routine results we attain using the relieved reamers in conjunction with the 30-degree reciprocating handpiece (Figs. 9–11).

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This article will analyze some of the most important research in the international literature today and the new guidelines for the use of the laser as a source of activation of chemical irrigants.

Laser-assisted endodontics

Preparation of the access cavity

The preparation of the access cavity can be performed directly with Erbium lasers, which can ablate enamel and dentine. In this case, the use of a short tip is recommended (from 4 to 6 mm), with diameters between 600 and 800 µm, made of quartz to allow the use of higher energy and power. The importance of this technique should not be underestimated.

Owing to its affinity to tissues richest in water (pulp and carious tissue), the laser allows for a minimally invasive access and at the same time allows for decontamination and removal of bacterial debris and pulp tissue. Access to the canal orifices can be accomplished effectively after the number of bacteria has been minimized, thereby avoiding the transposition of bacteria, toxins and debris in the apical direction during the procedure. Chen et al. demonstrated that bacteria are killed during cavity preparation up to a depth of 300 to 400 µm below the radiated surface. Moreover, Erbium lasers are useful in the removal of pulp stones and in the search for calcified canals.

Preparation and shaping of canals

The preparation of the canals with NiTi instruments is still the gold standard in endodontics today. In fact, despite the recognized ablative effect of Erbium lasers (2,780 and 2,940 nm) on hard tissue, their effectiveness in the preparation of root canals appears to be limited at the moment and does not correspond to the endodontic standards reached with NiTi technology. However, the Erbium, Chromium:YSGG (Er,Cr:YSGG) and the Erbium:YAG (Er:YAG) lasers have received FDA approval for cleaning, shaping and enlarging canals. A few studies have reported positive results for the efficacy of these systems in shaping and enlarging radicular canals.

Shoji et al. used an Er:YAG laser system with a conical tip with 80 percent lateral emission and 20 percent emission at the tip to enlarge and clean the canals using 10 to 40 mJ energy at 10 Hz, obtaining cleaner dentinal surfaces compared with traditional rotary techniques.

In a preliminary study on the effects of the Er:YAG laser equipped with a microprobe with radial emission of 200 to 400 µm, Kesler et al. found the laser to...
have good capability for enlarging and shaping in a faster and improved manner compared with the traditional method. The SEM observations demonstrated a uniformly cleaned dentinal surface at the apex of the coronal portion, with an absence of pulp residue and well-cleaned dentinal tubules. Chen presented clinical studies prepared entirely with the Er,Cr:YSGG laser, the first laser to obtain the FDA patent for the entire endodontic procedure (enlarging, clearing and decontaminating), using tips of 400, 320 and 200 µm in succession and the crown-down technique at 1.5 W and 20 Hz (with air/water spray 35/25 percent). Stabholz et al. presented positive results of treatment performed entirely using a Er:YAG laser and endodontic lateral emission microprobes. Ali et al., Matsuoka et al. and Jahan et al. used the Er,Cr:YSGG laser to prepare straight and curved canals, but in these cases, the results of the experimental group were worse than those of the control group. Using the Er,Cr:YSGG laser with 200 to 320 µm tips at 2 W and 20 Hz on straight and curved canals, they concluded that the laser radiation is able to prepare straight and curved (less than 10 degree) canals, while more severely curved canals demonstrated side effects, such as perforations, burns and canal transportation. Inamoto et al. investigated the cutting ability and the morphological effects of radiation of the Er:YAG laser in vitro, using 30 mJ at 10 and 25 Hz with a velocity of extraction of the fibre at 1 and 2 mm/seconds, again with positive results. Minas et al. reported positive results using the Er,Cr:YSGG laser at 1.5, 1.75 and 2.0 W and 20 Hz, with water spray.

The surfaces prepared with the Erbium laser are well cleaned and without smear layer, but often contain ledges, irregularities and charring with the risk of perforations or apical transportation. In effect, canal shaping performed by Erbium laser is still a complicated procedure today that can be performed only in large and straight canals, without any particular advantages.

Decontamination of the endodontic system

Studies on canal decontamination refer to the action of chemical irrigants (NaClO) commonly used in endodontics, in combination with chelating substances for better cleaning of the dentinal tubules (citric acid and EDTA). One such study is that of Berutti et al., who reported the decontaminating power of NaClO up to a depth of 130 µm on the radicular wall. Lasers were initially introduced in endodontics in an attempt to increase the decontamination of the endodontic system.

Decontamination with near infrared laser

Laser-assisted canal decontamination performed with the near infrared laser requires the canals to be prepared in the traditional way (apical preparation with ISO 25/30), as this wavelength has no affinity and therefore no ablative effect on hard tissue. The radiation is performed at the end of the traditional
endodontic preparation as a final means of decontaminating the endodontic system before obturation. An optical fibre of 200 µm diameter is placed 1 mm from the apex and retracted with a helical movement, moving coronally (in five to 10 seconds according to the different procedures). Today, it is advisable to perform this procedure in a canal filled with endodontic irrigant (preferably, EDTA or citric acid; alternatively, NaClO) to reduce the undesirable thermal morphological effects.

Using an experimental model, Schoop et al. demonstrated the manner in which lasers spread their energy and penetrate into the dentinal wall, showing them to be physically more efficient than traditional chemical irrigating systems in decontaminating the dentinal walls. The Neodymium:YAG (Nd:YAG; 1,064nm) laser demonstrated a bacterial reduction of 85 percent at 1 mm, compared with the diode laser (810nm) with 63 percent at 750 µm or less. This marked difference in penetration is due to the low and varying affinity of these wavelengths for hard tissue. The diffusion capacity, which is not uniform, allows the light to reach and destroy bacteria by penetration via the thermal effects.

Many other microbiological studies have confirmed the strong bactericidal action of the diode and Nd:YAG lasers, with up to 100 percent decontamination of the bacterial load in the principal canal. An in vitro study by Benedicenti et al. reported that the use of the diode 810 nm laser in combination with chemical chelating irrigants, such as citric acid and EDTA, brought about a more or less absolute reduction of the bacterial load (99.9 percent) of E. faecalis in the endodontic system.

**Decontamination with medium infrared laser**

Considering its low efficacy in canal preparation and shaping, using the Erbium laser for decontamination in endodontics requires the use of traditional techniques in canal preparation, with the canals prepared at the apex with ISO 25/30 instruments. The final passage with the laser is possible thanks to the use of long, thin tips (200 and 320 µm), available with various Erbium instruments, allowing for easier reach to the working length (1 mm from apex). In this methodology, the traditional technique is to use a helical movement when retracting the tip (over a five- to 10-second interval), repeating three to four times depending on the procedure and alternating radiation with irrigation using common chemical irrigants, keeping the canal wet, while performing the procedure (NaClO and/or EDTA) with the integrated spray closed.

The 3-D decontamination of the endodontic system with Erbium lasers is not yet comparable to that of near infrared lasers. The thermal energy created by these lasers is in fact absorbed primarily on the surface (high affinity to dentinal tissue rich in water), where they have the highest bactericidal effect on E. coli (Gram-negative bacteria), and E. faecalis (Gram-positive bacteria). At 1.5 W, Moritz et al. obtained an almost total eradication (99.64 percent) of these bacteria. However, these systems do not have a bactericidal effect at depth in the lateral canals, as
they only reach 300 µm in depth when tested in the width of the radicular wall.8

Further studies have investigated the ability of the Er,Cr:YSGG laser in the decontamination of traditionally prepared canals. Using low power (0.5 W, 10 Hz, 50 mJ with 20 percent air/water spray), complete eradication of bacteria was not obtained. However, better results for the Er,Cr:YSGG laser were obtained with a 77 percent reduction at 1 W and of 96 percent at 1.5 W.42

A new area of research has investigated the Erbium laser's ability to remove bacterial biofilm from the apical third,46 and a recent in vitro study has further validated the ability of the Er:YAG laser to remove endodontic biofilm of numerous bacterial species (e.g. A. naeslundii, E. faecalis, L. casei, P. acnes, F. nucleatum, P. gingivalis or P. nigrescens), with considerable reduction of bacterial cells and disintegration of biofilm. The exception to this is the biofilm formed by L. casei.47

Ongoing studies are evaluating the efficacy of a new laser technique that uses a newly designed both radial and tapered stripped tip for removal of not only the smear layer, but also bacterial biofilm.13 The results are very promising.

The Erbium lasers with "end firing" tips — frontal emission at the end of the tip — have little lateral penetration of the dentinal wall. The radial tip was proposed in 2007 for the Er,Cr:YSGG, and Gordon et al. and Schoop et al. have studied the morphological and decontaminating effects of this laser system (Fig. 2).48–50

The first study used a tip of 200 µm with radial emission at 20Hz with air/water spray (34 and 28 percent) and dry at 10 and 20 mJ and 20 Hz (0.2 and 0.4 W, respectively). The radiation times varied from 15 seconds to two minutes. The maximum bactericidal power was reached at maximum power (0.4 W), with a longer exposure time, without water in dry mode and with a 99.71 percent bacterial eradication.

The minimum time of radiation (15 seconds) with minimum power (0.2 W) and water obtained 94.7 percent bacterial reduction.48

The second study used a tip of 300 µm diameter with two different parameters of emission (1 and 1.5 W, 20 Hz), radiating five times for five seconds, with a cooling time of 20 seconds for each passage. The level of decontamination obtained was significantly high, with important differences between 1 and 1.5 W, with a thermal increase contained between 2.7 and 3.2 degrees C.49 The same group from Vienna studied other parameters (0.6 and 0.9 W) that produced a very contained thermal rise of 1.3 and 1.6 degrees C, respectively, showing a high bactericidal effect on E. coli and E. faecalis.50

The need to take advantage of the thermal effect to destroy bacterial cells, however, results in changes at the dentinal and periodontal level. It is important to evaluate the best parameters and explore new techniques that reduce the undesirable thermal effects that lasers have on hard- and soft-tissue structures to a minimum.

Morphological effects on the dentinal surface

Numerous studies have investigated the morphological effects of laser radiation on the radicular walls as collateral effects of root-canal decontamination and cleaning performed with different lasers. When they are used dry, both the near and medium
Infrared lasers produce characteristic thermal effects (Figs. 3, 4). Near infrared lasers cause characteristic morphological changes to the dentinal wall: the smear layer is only partially removed and the dentinal tubules are primarily closed as a result of melting of the inorganic dentinal structures. Re-crystallisation bubbles and cracks are evident (Figs. 5–8). Water present in the irrigation solutions limits the thermal interaction of the laser beam on the dentinal wall and, at the same time, works thermally activated by a near infrared laser or directly vaporized by a medium infrared laser (target chromophore) with its specific action (disinfecting or chelating). The radiation with the near infrared laser — diode (2.5 W, 15 Hz) and Nd:YAG (1.5 W, 100 mJ, 15 Hz) — performed after using an irrigating solution, produces a better dentinal pattern, similar to that obtained with only an irrigant.

Radiation with NaClO or chlorhexidine produces a morphology with closed dentinal tubules and presence of a smear layer, but with a reduced area of melting, compared with the carbonization seen with dry radiation. The best results were obtained when radiation followed irrigation with EDTA, with surfaces cleaned of the smear layer, with open dentinal tubules and less evidence of thermal damage. In the conclusion of their studies on the Erbium laser, Yamazaki et al. and Kimura et al. affirmed that water is necessary to avoid the undesirable morphological aspects markedly present when radiation with the Erbium lasers is performed dry. The thermal damage is reduced and the dentinal tubules are open at the top of the peri-tubular more calcified and less ablated areas. The inter-tubular dentine, which is richer in water however, is more ablated. The smear layer is vaporized by radiation with Erbium lasers and is mostly absent. Shoop et al., investigating the variations of temperature on the radicular surface in vitro, found that the standardised energies (100 mJ, 15 Hz, 1.5 W) produced a measured thermal increase of only 3.5 degrees C on the periodontal surface. Moritz proposed these parameters as the international standard of use for the Erbium laser in endodontics, claiming it as an efficient means of canal cleaning and decontamination (Figs. 9–12).

Even with Erbium lasers, it is advisable to use irrigating solutions. Alternatively, NaClO and EDTA can be utilized during the terminal phase of laser-assisted endodontic therapy with a resulting dentinal pattern, with fewer thermal effects. This represents a new area of research in laser-assisted endodontics. Various techniques have been proposed, such as laser-activated irrigation (LAI) and photon-initiated photoacoustic streaming (PIPS).

Photo-thermal and photomechanical phenomena for the removal of smear layer

George et al. published the first study that examined the ability of lasers to activate the irrigating liquid inside the root canal to increase its action. In this study, the tips of two laser systems — Er:YAG and Er,Cr:YSGG (400 µm diameter, both flat and conical tips) with the external coating chemically removed —
were used to increase the lateral diffusion of energy. The study was designed to irradiate the root canals that were prepared internally with a dense smear layer grown experimentally. Comparing the results of the groups that were laser radiated with the groups that were not, the study concluded that the laser activation of irrigants (EDTAC, in particular) brought about better cleaning and removal of the smear layer from the dentinal surfaces. In a later study, the authors reported that this procedure, using power of 1 and 0.75 W, produces an increase in temperature of only 2.5 degrees C without causing damage to the periodontal structures.

Blanken and De Moor also studied the effects of laser activation of irrigants comparing it with conventional irrigation (CI) and passive ultrasound irrigation (PUI). In this study, 2.5 percent NaClO and the Er,Cr:YSGG laser were used four times for five seconds at 75 ml, 20 Hz, 1.5 W, with an endodontic tip (200 µm diameter, with flat tip) held steady 5 mm from the apex. The removal of the smear layer with this procedure led to significantly better results with respect to the other two methods. The photomicrographic study of the experiment suggests that the laser generates a movement of fluids at high speed through a cavitation effect. The expansion and successive implosion of irrigants (by thermal effect) generates a secondary cavitation effect on the intra-canal fluids. It was not necessary to move the fiber up and down in the canal, but sufficient to keep it steady in the middle third, 5 mm from the apex. This concept greatly simplifies the laser technique, without the need to reach the apex and negotiate radicular curves (Fig. 13).

De Moor et al. compared the LAI technique with PUI and they concluded that the laser technique, using lower irrigation times (four times for five seconds), gives results comparable to the ultrasound technique that uses longer irrigation times (three times for 20 seconds). De Groot et al. also confirmed the efficacy of the LAI technique and the improved results obtained in comparison with the PUI. The authors underlined the concept of streaming due to the collapse of the molecules of water in the irrigating solutions used.

Hmud et al. investigated the possibility of using near infrared lasers (940 and 980 nm) with 200 µm fibre to activate the irrigants at powers of 4 W and 10 Hz, and 2.5 W and 25 Hz, respectively. Considering the lack of affinity between these wavelengths and water, higher powers were needed which, via thermal effect and cavitation, produced movement of fluids in the root canal, leading to an increased ability to remove debris and the smear layer. In a later study, the authors also verified the safety of using these higher powers, which caused a rise in temperature of 30 degrees C in the intra-canal irrigant solution but of only 4 degrees C on the external radicular surface. The study concluded that irrigation activated by near infrared lasers is highly effective in minimizing the thermal effects on the dentine and the radicular cement.

In a recent study, Macedo et al. referred to the main role of activation as a strong modulator of the reaction rate of NaOCl. During a rest interval of three minutes, the consumption of available chlorine increased significantly after LAI compared with PUI or CI.

**Photon initiated photoacoustic streaming (PIPS)**

The PIPS technique uses the Erbium laser (Powerlase AT/HT and LightWalker AT, both Fotona) and its interaction with irrigating solutions (EDTA, NaOCL or distilled water). The technique uses a different mechanism from the preceding LAI. It exploits exclusively the photoacoustic and photomechanical phenomena, which result from the use of subablative energy of 20 mJ at 15 Hz, with impulses of only 50 microseconds. With an average power of only 0.3 W, each impulse interacts with the water molecules with a peak power of 400 W creating expansion and successive “shock waves” leading to the formation of a powerful streaming of fluids in...
of Genoa and the University of Loma Linda School of Dentistry, University of Tennessee, Boston University, Louisiana State University and the Arizona School of Dentistry and Oral Health, are currently investigating the effects of this technique of root-canal decontamination and the removal of bacterial biofilm in the radiical canal. The results, which are about to be published, are very promising (Figs. 20–25).

Discussion and conclusion

Laser technology used in endodontics in the past 20 years has undergone an important evolution. The improved technology has introduced endodontic fibers and tips of a caliber and flexibility that permit insertion up to 1 mm from the apex. Research in recent years has been directed toward producing technologies (impulses of reduced length, “radial firing and stripped” tips) and techniques (LAI and PIPS) that are able to simplify its use in endodontics and minimize the undesirable thermal effects on the dentinal walls, using lower energies in the presence of chemical irrigants. EDTA has proved to be the best solution for LAI technique that activates the liquid and increments its chelating capacity and cleaning of the smear layer. The use of NaOCl increases its decontamination activity. Finally, the PIPS technique reduces the thermal effects and exerts a potent cleaning and bactericidal action thanks to its three dimensional streaming of fluids initiated by the photonic energy of the laser. Further studies are currently under way to validate these techniques (LAI and PIPS) as innovative technologies available to endodontics._

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Figs. 25a–d. Clockwise from lower left: Confocal microscope image of dentine (a). Autofluorescence with no sign of bacteria (b & c). 3-D view superimposed (d).
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Carestream Dental’s focused field cone beam CT (CBCT), the 9000 3D extraoral imaging system, is adding dimension to endodontic treatment planning. This CBCT imaging solution is consistently chosen by endodontists, as it provides the advantages of high resolution and relatively low dose focused field of view 3-D imaging at an affordable price.

Found in more than one-third of the graduate endodontic residency programs throughout the United States and Canada, the 9000 3D has been featured in numerous endodontic studies showing the efficacy of CBCT in endodontics. Most importantly, the 9000 3D system’s localized field of view limits irradiation to the patient, while providing highly detailed images of the region of interest.

The all-in-one 9000 3D is a versatile multi-modality imaging system designed to meet today’s needs. The unit comes with a focused-field of view (approximately 4 x 5 cm), but can be expanded through the “extended field of view” upgrade option that allows for capturing a full jaw in a single scan. In addition to its exceptional 3-D imaging capabilities, it also offers 2-D digital panoramic imaging with variable focal trough technology that’s crystal clear, every time. It even has a one-shot cephalometric imaging modality upgrade option. For practitioners who have been waiting to integrate cone beam computed tomography into their practice, this is the perfect option.

The growth of CBCT and ensuing adoption rates in endodontics is even more apparent at this year’s AAE educational sessions, where more than 10 percent include coverage on CBCT. “So many customers have shared with me the positive impact their practices have seen since the addition of the 9000 3D,” says Jordan Reiss, Carestream Dental’s U.S. sales director of endodontics. “We are excited to have our customers presenting cases at our AAE booth that exemplify not just how much our software sets us apart from other systems, but how high-resolution 3-D imaging is aiding in patient care.”

Carestream Dental proudly supports education throughout the year with webinars, seminars and hands-on workshops. The 2012 AAE Annual Session in Boston is a great example of the culmination of the company’s efforts to help endodontists understand this imaging modality even better. As a Diamond sponsor, Carestream Dental is delivering on AAE’s session goal of “Forging the Future” by sponsoring both the “Evidence-Based Endodontics” and “Exploring the Future” educational tracks.

The CS 3D imaging intuitive sharable software makes case collaboration easy. Carestream Dental’s imaging software is available free to share with referring doctors. With one click of a button, the full software and 3-D data can be placed on a flash drive or CD.

“One of the unique features of the 9000 3D system is the ease with which you can realign the viewing plane with the long access of the tooth,” says Dr. Randolph Todd, a diplomate of the ABE and a practicing endodontist in New York City. “The traditional ‘hunting’ to find the opening of the canal is no longer a problem. Canals not previously observable on 2-D radiographs are easily discernible and treated.”

Carestream Dental has a long history of manufacturing and selling dental imaging solutions under the PracticeWorks and Kodak Dental Systems brands. The 9000 3D system from Carestream Dental has been dominating the endodontic market since its release. Well known for its product line that includes digital intraoral sensors, intraoral cameras, and complete imaging software solutions, more than 1 million dentists in 120 countries use Carestream products.

For more information, contact Carestream Dental at (800) 944-6365 or visit www.carestreamdental.com/aae.
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Yankee Dental Congress 2013 will bring together thousands of brilliant minds to learn about the most innovative approaches, practices, and resources in dentistry.

Here is a sneak peak at a few education highlights:

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Loretta LaRoche
PERSONAL DEVELOPMENT

Kenneth Hargreaves, DDS
ENDODONTICS

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PRACTICE MANAGEMENT

Laney Kay, JD
INFECTION CONTROL

Cherilyn Sheets, DDS and Jacinthe Paquette, DDS
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Insert figure references in your article wherever they are appropriate, whether that is in the middle or end of a sentence, but before the period rather than after. Our preference is to have figure references noted in the appropriate place within the text as it helps the readers to orient themselves when moving through the article. In addition, please note:

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