Thermal injury through intraradicular heat transfer using ultrasonic devices

Precautions and practical preventive strategies

ALAN H. GLUSKIN, D.D.S.; CLIFFORD J. RUDDLE, D.D.S.; EDWIN J. ZINMAN, D.D.S., J.D.

ABSTRACT

Background. The use of ultrasonic energy is a highly efficient method of removing obstructions and cements within the root canal space when re-treatment or rehabilitation of that space is planned. The ultrasonic energy dislodges and removes cemented objects from the bonded interface of the canal wall. When using this method, there is less potential for structural loss or root damage and significantly less operator stress than when using other methods.

Case Descriptions. There is little evidence in published research of the considerable heat transfer that occurs during use of ultrasonic devices to remove posts, pastes and separated instruments in teeth. The authors present three cases of patients who experienced serious burn injuries during application of ultrasonic energy for restorative dentistry. The authors also offer techniques and strategies for safe and effective use of ultrasonic devices.

Clinical Implications. On the basis of the best available evidence, the authors recommend strategies to provide safe and effective therapy while using ultrasonic devices in intraradicular obstruction removal. The intent of the suggested protocols is to provide advanced and sophisticated therapies in a safe and regulated manner with patient safety as an overriding priority.

Key Words. Ultrasonic energy; intraradicular obstruction; heat transfer; unreasonable risk.

JADA CONTINUING EDUCATION ARTICLE 4

The use of ultrasonic energy has evolved into a highly efficient method of removing obstructions and cements within the root canal space when re-treatment or rehabilitation of that space is planned. This technique and an evolving armamentarium are used for post removal, paste and cement disintegration and separated instrument dislodgement. In less than a decade, it has gained rapid and widespread acceptance within the dental community as an adjunctive technique used in overcoming a formidable challenge. This has occurred because the ultimate goal in recovery of the root canal space is to ensure that the remaining dentin is sound and able to support the subsequent restoration structurally, as well as provide a restorative complex that is functionally healthy.[1] The use of ultrasonic devices has allowed dentists to embrace this important strategy.

Dentists should be mindful of excessive heat potential with ultrasonic devices even with the use of water coolants.

Postendodontic treatment outcomes may involve reinfection of the root canal space, a failed post-core complex that requires the recovery of the coronal canal, or an esthetic failure necessitating the replacement of a metallic dowel with a nonmetallic option that better meets the patient's esthetic expectations at the cervical area of the tooth's root. Often, one or more of these conditions would warrant the practitioner's removing an existing post to gain access to the canal space. Because conventional re-treatment often is the first choice of prudent practitioners before they turn to a surgical option to gain access to the canal, more and more clinicians are finding that ultrasonic devices are becoming indispensable in modern dental practice. In conjunction with ultrasonic devices, many clinicians use a number of mechanical aids such as post-pullers, tube-vise extractors, burs and solvents in tandem with ultrasonic energy.[2,3]

The use of vibrating mechanical energy is an efficient method of dislodging and removing cemented objects from the bonded interface of the canal wall. When using this method, there is less potential for structural loss or root damage and significantly less operator stress than when using other methods. Within the past two decades, techniques that use ultrasonic energy have evolved from periodontal therapies using ultrasonic devices to a myriad of applications within the specialty of endodontics.[4]

Ultrasonic energy is derived from one of two sources: magnetic resonance or piezoelectric energy. While it is known that piezoelectric energy devices operate in energy ranges that are higher than those of magnetorestrictive devices, most units that are used for post removal are within the higher energy ranges of operation.

BACKGROUND

Only a small number of investigators have cautioned that ultrasonic energy can be harmful; intense heat can be generated within a metallic object that has its distal end millimeters away from any cooling effects created by the operator or the device itself.[5-7] The use of heat and the potential for injurious heat transfer to dentin and bone have been investigated for a number of different devices used in endodontics and associated restorative procedures.[8-13] It generally is accepted that external root temperature increases that exceed 10 C produce irreversible bone and attachment damage, as well as dehydration effects on dentin often resulting in resorption.[14] Investigations of heat-induced injury have been in the literature for more than two decades, and many investigators have used the 10 C threshold to examine devices that produce heat in dentistry. Heat transferred to the pulp through conventional cavity preparations and restorative procedures has been well-documented in the literature.[15,16] Newer methods such as laser use on dentin have been studied for intrapulpal heat transfer. Lasers may jeopardize pulp vitality through heat transfer. In more recent research, temperature elevations between 0.5 and 32.0 C were registered in an energy- and length-of-time–dependent manner. Thinner dentin in the site of laser usage resulted in higher temperature elevations within the pulp. The time of application was a critical variable that mandated a "caveat" to monitor time limits in usage.

The use of vibrating mechanical energy is an efficient method of dislodging and removing cemented objects from the bonded interface of the canal wall.

When investigating devices that create heat within the root canal space, researchers found that the heat pluggers and spreaders produced heat transfer to the attachment that fell below the critical threshold for irreversible injury when it was used according to the manufacturer's specifications.[5] Other researchers investigating thermoplasticizing techniques have found similar results, specifically, that generated temperature increases on the root surface are not sufficiently high enough to cause damage to the tooth-supporting tissues, or they do not exceed the critical 10 C.[10,11] In an assessment of heat transfer to the root surface during post preparation with Peeso reamers and other post drills, researchers found that frictional heating caused by these engine-driven drills generated damaging temperatures on the root surface.[9,12]

There is little evidence in the literature of the considerable heat transfer that occurs when ultrasonic energy is used to remove posts, pastes and separated instruments from teeth. Two studies in recent years have cautioned practitioners about the need for adequate coolant and the need to counter heat buildup.[6,7] There are few recommendations found in the literature for how to accomplish the goal of countering heat buildup. Often, even the manufacturers provide generic admonitions for ultrasonic device usage and methods for cooling. Studies of intervals for application of energy consistently recognize that temperatures can rise to destructive levels within a few minutes without use of adequate and sufficient coolant.[6,7]

The general recommendation from research regarding heat buildup is that care should be taken to not continue using ultrasonic devices over prolonged periods. In addition, clinical protocols on how to safely remove posts without causing thermal damage to the adjacent periodontal tissues are needed. A 2003 study of ultrasonic heat transfer by Satterthwaite and colleagues[6] found that 75 percent of samples in both ceramic and stainless steel groups had external root temperatures that exceeded the critical 10 C threshold within the first five minutes. All of the samples were vibrated with a water spray coolant directed to the ultrasonic tip. The researchers found no significant differences when they compared the effects of heat generated by ceramic and stainless steel posts during removal. They cautioned, however, against extrapolating in vitro data of root temperature increases to the in vivo clinical situation of a circulatory system within the attachment apparatus capable of dissipating heat. The results of the study, however, showed temperature increases that would have exceeded greatly the dissipation effects of the periodontal vasculature. Accordingly, Satterthwaite and colleagues warned readers to maximize the amount of coolant used and minimize application time.

PRODUCT SAFETY

One ultrasonic device manufacturer's warning states, in part, "Irrigate abundantly and continuously."[17] This clinical usage advice does not expressly address heat transfer effects since it lacks a concomitant admonition to allow for post cooling periodically, as well as to monitor for post overheating.

Dental device manufacturers require U.S. Food and Drug Administration (FDA) approval and must demonstrate safety and efficacy before marketing the device.[18] When seeking FDA approval, some manufacturers may claim their products are similar to existing FDA-approved devices so they can piggyback onto existing FDA-approved research rather than conduct new independent research.[19] Accordingly, some dental devices are marketed without undergoing long-term studies to assess adverse events. A device needs to be substantially equivalent to previous FDA-approved devices to be permitted to do such marketing.[20]

Manufacturers are obligated to conduct postmarket surveillance and must report adverse events to the FDA. Conversely, dentists are not legally obligated to report adverse events to the FDA, but they may do so on a confidential voluntary basis. Disclosure of the patient's name to the FDA also is voluntary, but it should be done with the patient's consent. Unfortunately, only 1 percent of clinicians report adverse events to the FDA because this requirement is voluntary rather than compulsory.[21] Manufacturers must report serious injuries that necessitate medical or surgical intervention by a health care professional to the FDA under the Mandatory Medical Device Reporting regulation.[22] Accordingly, clinicians are encouraged to voluntarily report adverse events not only for ultrasonic devices but all materials and devices so that manufacturers and the FDA can issue warnings or manufacturers can incorporate these warnings in product package inserts. One can make adverse event reports by contacting the FDA by telephone at 1-800-FDA-1088 or by fax at 1-800-FDA-0178 and requesting the FDA Medical Products Reporting Program (MedWatch) form (FDA form 3500). The back portion of the Physicians' Desk Reference also contains a MedWatch adverse event form.

CASE REPORTS

The safe use of ultrasonic devices is paramount. Since dentists are taught to be cautious with heat-generating devices contacting hard or soft tissue, they should be mindful of excessive heat potential with ultrasonic devices even with the use of water coolants. Ultrasonic device use should include monitoring intervals to check for overheating and permit the post to cool.

The following three cases are from the legal files of one of the authors (E.J.Z.) who practices in the San Francisco Bay area.[23] Extrapolating these data suggests that for the entire U.S. population, the number (incidence) of overheating incidents may be significant.

Case 1. A 50-year-old woman with no significant medical history was scheduled to have a metallic post removed from tooth no. 9 and to have it replaced with a composite glass-fiber post for the esthetic reason of gray "show-through" at the cervical area of the crown. In addition, teeth nos. 8 and 10 were to receive esthetic posts in preparation for crowns. The patient wore a rubber dam during treatment and experienced some pain during the course of post removal, even while anesthetized. The removal process lasted about an hour.

Tooth no. 9 was extracted after 48 hours owing to burn injuries to the teeth and their supporting structures that occurred during heat transfer. The patient underwent several attempts to repair the alveolar ridge by distraction osteogenesis (Figure 1).

Case 2. The patient was a 35-year-old woman with a noncontributory medical history. The clinician was removing the post from tooth no. 7 because of a crown fracture that required a rehabilitation of the post-core complex and a retreatment of the pre-existing endodontic therapy. The dentin structure of the lateral incisor was thin, and the post was long, extending to the apical one-third. The burn occurred during ultrasonic removal of the post. The loss of the tooth and bone in this case created a difficult esthetic problem for the patient (Figure 2, page 1290).

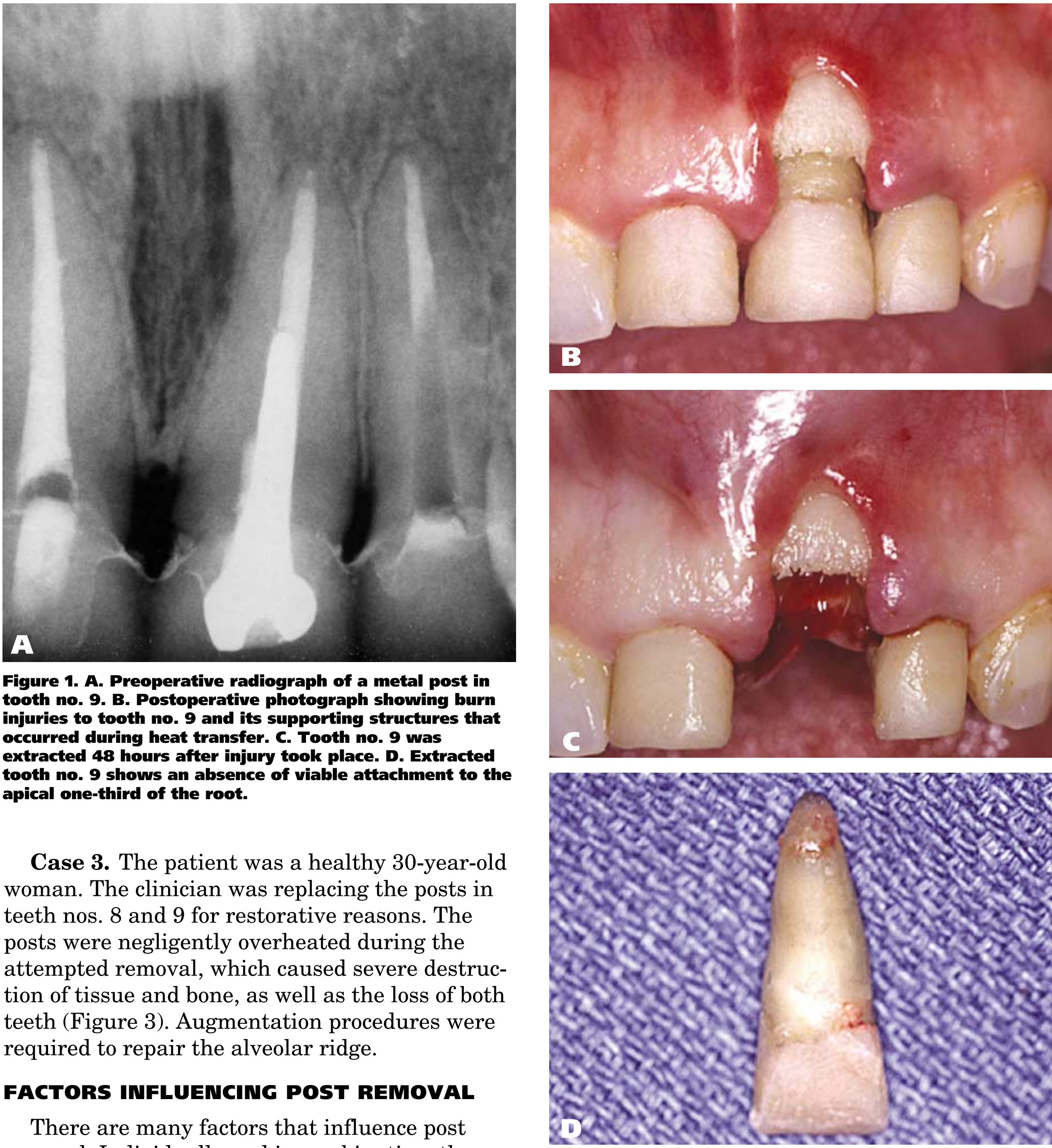

Figure 1. A. Preoperative radiograph of a metal post in tooth no. 9. B. Postoperative photograph showing burn injuries to tooth no. 9 and its supporting structures that occurred during heat transfer. C. Tooth no. 9 was extracted 48 hours after injury took place. D. Extracted tooth no. 9 shows an absence of viable attachment to the apical one-third of the root.

Case 3. The patient was a healthy 30-year-old woman. The clinician was replacing the posts in teeth nos. 8 and 9 for restorative reasons. The posts were negligently overheated during the attempted removal, which caused severe destruction of tissue and bone, as well as the loss of both teeth (Figure 3). Augmentation procedures were required to repair the alveolar ridge.

FACTORS INFLUENCING POST REMOVAL

There are many factors that influence post removal. Individually and in combination, these factors should be considered carefully before commencing with any treatment.[24]

Post type. One significant factor that influences post removal is the post type.[25,26] Posts can be categorized into parallel versus tapered, active versus nonactive, and metallic versus nonmetallic materials. Composite and ceramic posts are used increasingly in restorative dentistry, as they mimic more closely the biomechanics of the natural tooth in terms of function and esthetics, though they are more difficult to remove than are their metal counterparts.[27,28]

Cementing agent. A second factor that influences post removal is the cementing agent that is used. Posts retained with classic cements like zinc phosphate generally can be removed; however, posts bonded into the root canal space with materials like resin-based composites or glass

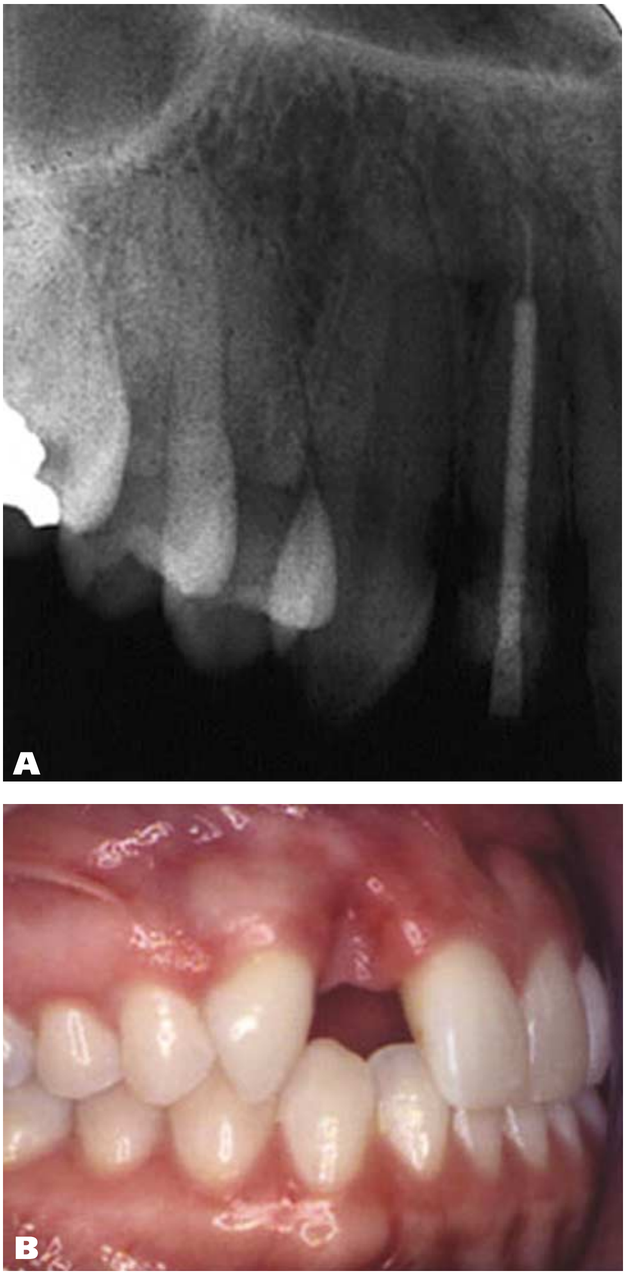

Figure 2. A. Preoperative radiograph of the post in tooth no. 7. B. Postoperative photograph showing healing of burn injury with resultant bony defect.

Figure 3. A. Postoperative burn on the gingiva and lip after the posts were removed. B. Photograph 48 hours after the burn injury occurred.

ionomer cements often are more difficult to remove.[29]

Tooth anatomy. Another factor that influences successful post removal is tooth anatomy. Clinicians should have knowledge of and respect for the morphology of the pulpal space and be familiar with the typical range of variation within each tooth type. For example, it is important to know the length, circumferential dimensions and curvature of any given root including, if present, the depth of an external concavity. This information is best obtained by taking three different horizontally angulated preoperative radiographs. Three radiographs can provide more information than one and help clinicians visualize the length, diameter and direction of the post.

Clinicians should be familiar with the radiographic characteristics associated with metallic and nonmetallic posts.[30] The relative radiodensity of a titanium post or a titanium alloy post can appear similar, or even identical, to gutta-percha when viewed radiographically.

Other influences. Other factors that influ-

Figure 4. An ultrasonic device instrument used with copious irrigation.

ence successful post removal are the available interocclusal space, the existing restoration and whether the coronal-most aspect of the post extends into the pulp chamber or is fractured subcrestally.[1,31] In general, post removal becomes more challenging when moving from anterior to posterior teeth. The difficulty in removing a post increases substantially in furcated teeth that contain multiple posts joined coronally by a buildup or interlocking keyway.

Perhaps the most critical factors influencing successful post removal are clinical judgment, training and experience in the use of the best technologies and techniques.[3,32] Indeed, a root can be structurally weakened, perforated or fractured during any phase of re-treatment.[33,34] Intraradicular heat transfer and thermal injuries are clinical realities when ultrasonic procedures are performed incorrectly. Consequently, clinicians should recognize that a surgical approach or an extraction may be a more prudent and safer choice at times.

POST REMOVAL TECHNIQUES

Once straight-line access into the pulp chamber has been accomplished, all core materials have been eliminated and the post is fully exposed, clinicians can use various techniques that have been advocated to remove a post.[2,28,35] One technique used frequently involves a piezoelectric device in conjunction with specific ultrasonic devices.[4,36] The most active distal end of an appropriately designed ultrasonic device is used to transfer energy to, as well as vibrate against and potentially dislodge, the post. The selected ultrasonic device is energized at the lowest power setting that will perform the clinical task safely and is moved up, down and around the exposed length of the post. When ultrasonic procedures are performed, especially at higher energy levels for longer periods and against larger and more conductive posts, heat is generated.[6] As such, the field should be flushed with water frequently to decrease heat buildup and the potential for dangerous heat transfer to the attachment apparatus[3] (Figure 4). Fortunately, when a water coolant is used frequently and voluminously, the danger for heat transfer is minimized, and the heat is further dissipated owing to the moisture content in the attachment apparatus.[5,6,37] In general, after removing all restorative materials from the pulp chamber, most posts can be removed safely within approximately 10 minutes.[25,38]

FACTORS INFLUENCING HEAT TRANSFER

Little has been reported in the literature that identifies the factors that influence heat transfer during an attempted post removal using an ultrasonic device. There are several factors that influence heat transfer and the potential for thermal injury. Specifically, there is virtually no research information available that quantifies the optimal magnitude of energy for any given ultrasonic device that maximizes clinical efficiency yet mitigates dangerous heat transfer. Additionally, little is reported regarding the length of time an instrument at any ultrasonic power setting can vibrate against a post without causing thermal injury. Protocols need to be developed to measure heat transfer based on the length, diameter and configuration of a post and the type of material from which it is constructed.

Another factor influencing heat transfer when an ultrasonic device is being used in an attempt to remove a post is the thickness of the remaining dentin. For example, many posts observed on radiographs to be centered within a root often are extremely close to the external root surface owing to surface concavities. A recent investigation showed that when a no. 4 Gates-Glidden drill was used to prepare a post space in the distal root of a mandibular molar, the residual dentin thickness was less than 1.0 millimeter in 82 percent of the cases.[39] Fortunately, adequate water coolant can reduce heat transfer safely and virtually eliminate the risk of thermal injury to the tooth. However, the literature does not provide sufficient guidelines for how often a clinician should irrigate the tooth to dissipate the heat, how long ultrasonic energy should be applied and whether cool-down intervals are necessary to prevent cumulative damage. Also unknown is what volume of coolant is effective in maintaining a safe physiological temperature. Additional research needs to be performed, data need to be gathered and information needs to be published to clarify how each factor, or combination of factors, influences heat transfer.

RECOMMENDED PROTOCOLS

Based on the best available evidence to date, we recommend the following protocols to provide safe and effective therapy using ultrasonic devices in intraradicular obstruction removal.

- Attempt to radiographically image residual dentin thickness for the working level within the root (this will help judge heat transfer rates to the attachment); thicknesses less than 1 mm, in combination with metallic or ceramic posts, will transmit heat rapidly.
- Use devices that allow water to reach the working end of the ultrasonic tip to provide maximum cooling effect.
- Use copious water spray and effective suction at a continuous rate; there is ample evidence that when the working end of any ultrasonic device is deep within the root, heat generation occurs rapidly.
- Monitor the post temperature at one- to two-minute intervals; this seems to be the most prudent standard given the evidence that extreme temperatures on the root surface can be reached in five minutes even when a coolant is used.
- When possible, monitor heat buildup in the post by touching it; even a gloved finger will be able to sense a post overheating.
- If post removal attempts are continued beyond 10 minutes, allow for two-minute rest intervals (using timers with beepers) between ultrasonic device applications; heat buildup appears to be dissipated in stages, and recovery of physiological temperatures occurs slowly.
- Use a refrigerant spray applied to a cotton swab or an ice stick to cool down the post if necessary; the expansion-contraction effects of this strategy are minimal compared with the severe outcomes of a burn injury.
- Use post-pullers and other viselike devices as adjuncts to ultrasonic energy.

CONCLUSIONS

Each dental procedure has a variable degree of inherent risk. The standard of care requires that the clinician avoid unreasonable risks that may harm the patient. Treatment is deemed negligent when a reasonably careful clinician should have foreseen and prevented unreasonable risk of harm to the patient. Failure to follow the dictates of sound biological practice increases the risk of negligently induced deleterious results.

While the cases presented in this article may be disconcerting for any practitioner to consider, we must recognize that the figures in the cases serve to promote prudent practice safeguards. Our ethical obligation to protecting patient safety is achieved when dentistry can provide advanced and sophisticated therapies in a safe and controlled manner with patient safety as an overriding priority. ■

Dr. Gluskin is a professor and the chair, Department of Endodontics, Arthur A. Dugoni School of Dentistry, University of the Pacific, 2155 Webster St., San Francisco, Calif. 94115, e-mail "agluskin@pacific.edu". Address reprint requests to Dr. Gluskin.

Dr. Ruddle is the founder and the director, Advanced Endodontics, Santa Barbara, Calif., is an adjunct assistant professor, Arthur A. Dugoni, School of Dentistry, University of the Pacific, San Francisco, and is in private practice, Santa Barbara.

Dr. Zinman maintains a private law practice, San Francisco.

1. Goon WW. Managing the obstructed root canal space: rationale and techniques. Ensuring the soundness of the remaining tooth structure. J Calif Dent Assoc 1991;19(5):51-60.
2. Machtou P, Sarfati P, Cohen AG. Post removal prior to retreatment. J Endod 1989;15(11):552-4.
3. Ruddle CJ. Nonsurgical endodontic retreatment. J Calif Dent Assoc 2004;32(6):474-84.
4. Ruddle CJ. Nonsurgical endodontic retreatment. In: Pathways of the pulp. 8th ed. Cohen S, Burns RC, eds. St. Louis: Mosby; 2002: 875-929.
5. Romero AD, Green DB, Wucherpfennig AL. Heat transfer to the periodontal ligament during root obturation procedures using an in vitro model. J Endod 2000;26(2):85-7.
6. Satterthwaite JD, Stokes AN, Frankel NT. Potential for temperature change during application of ultrasonic vibration to intraradicular posts. Eur J Prosthodont Restor Dent 2003;11(2):51-6.
7. Bailey GC, Cunnington SA, Ng YL, Gulabivala K, Setchell DJ. Ultrasonic condensation of gutta-percha: the effect of power setting and activation time on temperature rise at the root surface—an in vitro study. Int Endod J 2004;37:447-54.
8. Atrizadeh F, Kennedy J, Zander H. Ankylosis of teeth following thermal injury. J Periodontal Res 1971;6(3):159-67.
9. Saunders EM, Saunders WP. The heat generated on the external root surface during post space preparation. Int Endod J 1989;22(4): 169-73.
10. Barkhordar RA, Goodis HE, Watanabe L, Koumdjian J. Evaluation of temperature rise on the outer surface of teeth during root canal obturation techniques. Quintessence Int 1990;21(7):585-8.
11. Weller RN, Koch KA. In vitro radicular temperatures produced by injectable thermoplasticized gutta-percha. Int Endod J 1995;28(2): 86-90.
12. Hussey DL, Biagioni PA, McCullagh JJ, Lamey PJ. Thermographic assessment of heat generated on the root surface during post space preparation. Int Endod J 1997;30(3):187-90.
13. Kreisler M, Al-Haj H, d'Hoedt B. Intrapulpal temperature changes during root surface irradiation with an 809-nm GaAIAs laser.

Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2002;93(6):730-5.
14. Eriksson AR, Albrektsson T. Temperature threshold levels for heat-induced bone tissue injury: a vital-microscopic study in the rabbit. J Prosthet Dent 1983;50(1):101-7.
15. Abrams H, Barkmeier WW, Cooley RL. Temperature changes in the pulp chamber produced by ultrasonic instrumentation. Gen Dent 1979;27(5):62-4.
16. Zach L, Cohen G. Pulp response to externally applied heat. Oral Surg Oral Med Oral Pathol 1965;19:515-30.
17. Suprasson P5 Booster. User's manual, Version 3. Mt. Laurel, N.J.: Satelec; 2000.
18. Federal Food, Drug and Cosmetic Act, 21 U.S.C. §301, et. seq. (1938)
19. Federal Food, Drug and Cosmetic Act (21 U.S.C. §301, et. seq.) as amended by the Medical Device Amendments of 1994.
20. Lohr v. Medronics, Inc. (1996) 518 US 470.
21. Kessler DA. Introducing MEDWatch: a new approach to reporting medication and device adverse effects and product problems. JAMA 1993;269(21):2765-8.
22. Code of Federal Regulations title 21, Part 803, Section 803.1, et. seq. (2000)
23. Edwin J. Zinman legal file: Case 307495; Case C02-02389; Case no. 315630.
24. Ruddle CJ. Nonsurgical retreatment. J Endod 2004;30(12):827-45.
25. Yoshida T, Gomyo S, Itoh T, Shibata T, Sekine I. An experimental study of the removal of cemented dowel-retained cast cores by ultrasonic vibration. J Endod 1997;23(4):239-41.
26. Bergeron BE, Murchison DF, Schindler WG, Walker WA 3rd. Effect of ultrasonic vibration and various sealer and cement combinations on titanium post removal. J Endod 2001;27(1):13-7.
27. Gluskin AH, Ahmad I, Herrero DB. The aesthetic post and core: unifying radicular form and structure. Pract Proced Aesthet Dent 2002;14(4):313-22.
28. Gesi A, Magnolfi S, Goracci C, Ferrari M. Comparison of two techniques for removing fiber posts. J Endod 2003;29(9):580-2.
29. Gomes AP, Kubo CH, Santos RA, Santos DR, Padilha RQ. The influence of ultrasound on the retention of cast posts cemented with different agents. Int Endod J 2001;34(2):93-9.
30. Kleier DJ, Shibilski K, Averbach RE. Radiographic appearance of titanium posts in endodontically treated teeth. J Endod 1999;25(2): 128-31.
31. Smith BJ. Removal of fractured posts using ultrasonic vibration: an in vivo study. J Endod 2001;27:632-4.
32. Ruddle CJ. Micro-endodontic nonsurgical retreatment. Dent Clin North Am 1997:41(3):429-54.
33. Abbott PV. Incidence of root fractures and methods used for post removal. Int Endod J 2002;35(1):63-7.
34. Altshul JH, Marshall G, Morgan LA, Baumgartner JC. Comparison of dentinal crack incidence and of post removal time resulting from post removal by ultrasonic or mechanical force. J Endod 1997;23(11):683-6.
35. Johnson WT, Leary JM, Boyer DB. Effect of ultrasonic vibration on post removal in extracted human premolar teeth. J Endod 1996;22:487-8.
36. Dixon EB, Kaczkowski PJ, Nicholls JI, Harrington GW. Comparison of two ultrasonic instruments for post removal. J Endod 2002;28(2):111-5.
37. Sweatman TL, Baumgartner JC, Sakaguchi RL. Radicular temperatures associated with thermoplasticized gutta-percha. J Endod 2001;27(8):512-5.
38. Buoncristiani J, Seto BG, Caputo AA. Evaluation of ultrasonic and sonic instruments for intraradicular post removal. J Endod 1994;20(10):486-9.
39. Kuttler S, McLean A, Dorn S, Fischzang A. The impact of post space preparation with Gates-Glidden drills on residual dentin thickness in distal roots of mandibular molars. JADA 2004:135:903-9.