Revolutionary Advances, Part 3: Pursuit of the 3-D Cork

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This is part 3 of a 3-part article series. Parts 1 and 2 of Dr. Simons' article were published in the May and August 2011 issues of Dentistry Today *and can be found in our archived articles at dentistrytoday.com.*

Exciting times are upon us! As in many areas of dental specialty, the recent boom in technology has revolutionized the practice of endodontics. These technological advances have allowed us to evolve and increase our ability to provide ever improving successful outcomes. This forward thinking enables us to confidently face challenges that arise in clinical practice. For example, providing long-term endodontic success was needed for the foundation of the full-mouth reconstruction of the world's tallest man (Figure 1). This 3-part article series was written to show some of the ways this recent explosion in technology has impacted the endodontic profession; the first article illustrated how cone beam computed tomography (CBCT) completely changed endodontic diagnosis as well as displayed its potential in guiding treatment of complex pulpal anatomy;[1] the second article demonstrated how recent technological advances have significantly increased our efficacy in safe, deep, lateral, and active irrigation;[2] and this, the third article in the series, focuses on why the consistent delivery of a precise 3-dimensional (3-D) seal of homogenous gutta-percha into all ramifications within root canal systems (which the author refers to as *corkage*) is an imperative objective for success. Emphasis will be given to the thermomechanical properties of gutta-percha and the placement of the coronal seal as the final phase of successful endodontic treatment. Finally, a few cases are included in order to highlight the impact of these advances in an attempt to bring this series full circle clinically.

Figure 1. The tallest man in documented history (standing at 8'4") required endodontic therapy as the foundation for a full-mouth reconstruction.

HISTORY OF GUTTA-PERCHA AND ITS INTRODUCTION INTO ENDODONTICS

Gutta-percha was introduced into dentistry 164 years ago and it remains the most commonly used material to fill root canal systems today. At a minimum, this represents an acknowledgement of its proven biologic and mechanical acceptability. Some of the properties of gutta-percha that are advantageous for its use as an endodontic filling material are that it is natural, inert, highly biocompatible,[3] dimensionally stable,[4] thermoplastic,[5] compactable,[6] radiopaque,[7] dissolvable,[8] and the zinc oxide provides antibacterial activity.[9] Understanding the history and thermomechanical properties of gutta-percha holds value in our pursuit to maximize its potential.

Gutta-percha's history started in Southeast Asia. Due to its native origin, the Chinese and Malays observed and used gutta-percha long before it came westward.[10-11] English Royals and wealthy explorers were the next privy to the unique properties that were exhibited by trees found throughout the Malaysian islands. Gutta-percha was not introduced to commoners until the middle of the 1600s when the renowned English explorers, the Tradescants, displayed this novel "mazer wood" that could be warmed and molded to any form.[12] However, another 200 years went by before gutta-percha found practical uses in the western world. At the birth of the dynamic electricity era, gutta-percha was found to be the most desirable insulator of undersea cables. This was due to its inertness at low temperatures and because, when warmed, it could be molded around telegraph wire. Ernst von Siemans was the first to successfully insulate an underwater cable with the use of gutta-percha in 1848.[11,13] Gutta-percha cable was then successfully laid across the Atlantic Channel with longer undersea cables to follow. Gutta-percha also gained popularity at the time as it replaced feather-filled golf balls. These "gutties" were cheaper, went farther and could be warmed and pressed back into form after a round of golf. Infatuation ensued as many industries of the time attempted to capture the desirable properties of gutta-percha. It was employed for the manufacture of everything from corks, cements, surgical instruments, gloves, carpets, globes, pillows, musical instruments, sheathing for ships, and yes, even for filling dental cavities. However, the boom of gutta-percha ended in most sectors by the end of the 19th century due the discovery of rubber. Ironically, the reason for its downfall in most

Figure 2. Dr. Herbert Schilder was a pioneering clinician who had an overwhelming impact on clinical endodontics. Despite his passing in 2006, his relentless devotion to excellence continues to impact the levels of endodontic success enjoyed today.

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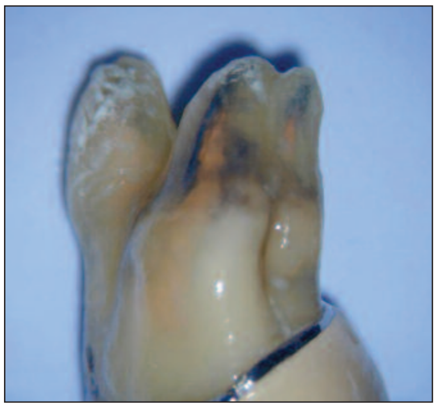
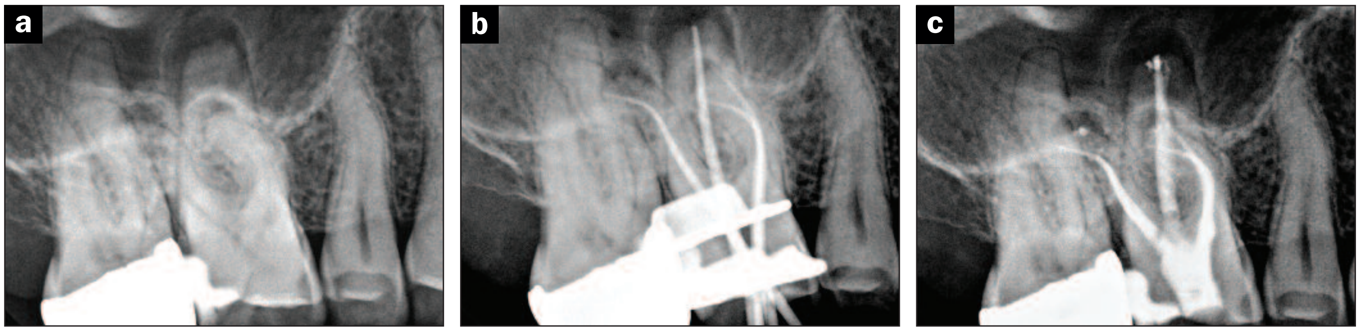


Figure 3. Pigmentation, due to pulpal degradation and bacterial biofilms, can be visualized at the apex of this failing maxillary molar. *Courtesy of Dr. Marga Ree.*



Figures 4a to 4c. This case highlights challenges that arise when sealing complex pulpal anatomy, such as delivering heat to the apical region of the curved 27 mm distobuccal canal and safely sealing the 3-dimensional anatomy of the palatal root.

Figure 5. Endodontic success would be better in this case if a permanent coronal seal were placed directly upon obturation. Potential contamination, prior to sealing the remainder of the root canal system, decreases its overall prognosis.

Figure 6. Long-term endodontic success is greater in this relatively similar case as the *immediate placement* of a bonded core was accomplished as the final phase of successful treatment.

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industries was due to its plasticity at relatively low temperatures, yet this has proven to be most advantageous for 3-D filling of root canal systems.

In 1847, Edwan Truman introduced gutta-percha as a temporary dental filling material.[14] Patented in 1848 and used extensively, Hill's stopping was a preparation consisting primarily of bleached gutta-percha, carbonate lime, and quartz.[15] In 1867, Bowman was the first to demonstrate gutta-percha's use as a root canal filling material.[16] By 1887, the S.S. White Company was manufacturing and distributing gutta-percha points. In the infancy of its use in endodontics, the techniques advocated for filling cleaned canals was to stuff as much gutta-percha into the root as possible. Many still employ this primative technique today.

Our downfall in adequately sealing root canal systems first became apparent with the introduction of radiographs in the early 1900s. Practitioners then visualized this complication in greater detail when Dr. Walter Hess revealed the complexities of root canal systems for the first time in 1925.[17] His landmark study shot vulcanized rubber throughout the pulpal systems of more than 3,000 extracted teeth. Once the teeth were demineralized, the vast complexities that exist within root canal systems were left for evaluation and study.

This knowledge of the intricacies and randomness of pulpal systems encouraged many to improve upon techniques for obturation. To this end, Dr. Herbert Schilder (Figure 2) had a profound impact. As in many areas, innovation is only realized when gifted individuals take the initiative toward progress. In his pursuit of a dense 3-D seal of the entire root canal system, Dr. Schilder recognized the importance of a firm grasp of the thermomechanical properties of gutta-percha. He wrote that this was crucial in order for us to benefit from gutta-percha's maximum potential. Since vision without a plan is hallucination, he set forth an exhaustive amount of work to unlock these properties. Dr. Schilder's work literally sculpted our understanding of gutta-percha and engineered its use in endodontics.

In the final analysis of our success, it is the sealing off of the complex root canal system from the periodontal ligament and bone which ensures the health of the attachment apparatus against breakdown of endodontic origin.[3] This objective for success can be difficult to accomplish clinically. Figure 3 illustrates the ability of bacteria to colonize within extremely small areas of an obturated root canal system. This potential complication is well-established. In fact, a review of the literature done more than 50 years ago attributed about 60% of treatment failures to our inability to seal the entire root canal space.[18] The maxillary molar presented in Figures 4a to 4c illustrates increased levels of sophistication that arise when attempting to 3-dimensionally mold gutta-percha into complex root canal systems. The multiple curvatures present in the 27 mm long distobuccal (DB) root presented difficulty in delivering heat to accomplish deep, apical 3-D molding, whereas the anatomical complexities present at the apex of the palatal root were challenging to seal accurately and safely.

CLINICALLY IMPORTANT THERMOMECHANICAL PROPERTIES OF GUTTA-PERCHA

It has been said that there is value in starting with the endpoint. With this in mind, this section can be started by declaring that compaction of thermoplasticized gutta-percha can compensate for potential shrinkage that can occur when warming gutta-percha.[19] Although a universal technique for the delivery of a consistent, dense, precise seal of the entire root canal space has not yet surfaced, it seems that most innovative techniques utilize heat to help 3-dimensionally mold gutta-percha. Nonetheless, a full understanding of the properties of the materials that we employ is necessary for their optimization.

Gutta-percha is the naturally occurring polymer of 1,4 trans-polyisoprene. The sap from a large genus of Malaysian trees is the resource of these naturally occurring long chain polyisoprenes. At low temperatures, the 1,4 trans-polyisoprene (gutta-percha) chains are found in 2 stable forms. In 1942, Bunn was the first to demonstrate these 2 distinctly different crystalline forms of gutta-percha.[20] He defined these 2 distinct orientations in which gutta-percha exists as the alpha and beta phases. Gutta-percha occurs naturally in the alpha crystallization phase. When heat is applied, gutta-percha softens and increases in size as the molecules vibrate and their attraction loosens. High temperatures affect the molecular arrangement of these long chain polymers. If alpha gutta-percha is raised above its molecular phase transition temperature, it reorganizes into the beta crystallization phase upon cooling (unless cooling occurs at a rate of less than 0.5° C per hour, to which the alpha phase recrystallizes). If temperature is raised even higher, a third amorphous phase is then produced.[21] Most dental grade gutta-percha is in the beta crystalline form due to processing. The transformation temperatures for a wide array of dental grade gutta-percha were determined to be 42 to 49° C for the beta to the alpha and 53 to 59° C for the alpha to amorphous transition.[21]

The thermomechanical property of gutta-percha of having temperature-mediated molecular phase transformation shifts holds clinical significance. If these phase transformation temperatures are reached, gutta-percha decreases in volume upon cooling. This is due to a rapid decrease in volume upon recrystallization from the amorphous or alpha phase to the beta phase.[19] Complications related to shrinkage can be compensated for, if compaction pressure is held during this cooling time.[19] Furthermore, if gutta-percha is heated for molding in the clinical setting but the beta to alpha phase transition is not reached, then shrinkage problems are eliminated. Interestingly, gutta-percha has been shown to have the potential to increase 1% in size compared to its preoperative room temperature volume if phase transformation shifts are avoided when warming.[19] Furthermore, gutta-percha has been demonstrated to be moldable apically at temperatures 2 to 4° C above body temperature.[22]

Another clinically significant finding related to phase transitions and volume changes was found with heat cycling. It has been demonstrated that, upon a multiple wave of heat delivery, shrinkage does not occur after the first cycle of heat delivery and cooling.[19] Nonetheless, when employing heat delivery to gutta-percha that exceeds phase transformation temperatures, we need to stay mindful of shrinkage possibilities. Stated again, the most significant finding related to phase transitions and volume changes that may occur during warm gutta-percha techniques is that holding pressure upon vertical compaction, as the softened or even liquefied melt crystallizes, can compensate for the minimal shrinkage that occurs. Furthermore, gutta-percha regains its inert stability once compaction forces compensate for shrinkage upon cooling.

Another thermomechanical property of gutta-percha with clinical significance is its relative inability to transmit heat for softening and 3-D molding. It has been recorded that heat does not transfer through gutta-percha more than a few millimeters from the deepest point of heat penetration.[22] Often, this becomes relevant due to the vastness of challenging anatomical complexities encountered clinically. Again, Figure 4c highlights this current limitation to warm gutta-percha for 3-D molding in deep, difficult-to-reach areas of pulpal systems such as at the apical end of this maxillary molar's long, curved DB canal.

CORONAL SEAL

Discussion of the 3-D seal of the entire root canal system would be incomplete without emphasizing the importance of the placement of the coronal seal as the final phase of successful endodontic treatment. Once the 3-D intricacies of a root canal system have been evaluated, shaped, and disinfected, then success ultimately lies in our ability to seal this complex and vulnerable system from the pathogenic source of endodontic disease—the oral flora.[23,24] Our overall endodontic success rates would be higher *if all clinicians placed the coronal seal immediately after the canals are sealed.* This is the time when the isolated pulpal system is at its highest level of disinfection. We know that endodontic disease emanates from the oral cavity and we strive to disinfect and seal the smallest of crevices within the canal systems. It is therefore logical to seal the main portal of entry for these pathogens in our effort to prevent future disease. Figure 5 illustrates a lack of respect for this well understood requirement for success. A relatively similar case treated in Figure 6 has a significantly increased overall prognosis due to the placement of the bonded core directly after obturation.

In addition to common sense, the amount of quality research that supports this important final objective for successful endodontic treatment is substantial.[25-33] Recently, an impressive study was performed by Delta Dental in an effort to evaluate the success of endodontic outcomes. In assessing over 1.4 million endodontic cases over an 8-year period, they found a success rate of 97%. Although impressive, a profound side note was that in the 3% of cases that failed, 85% did not have coronal coverage.[34] Imagine the achievable success rate of modern endodontic therapy should a thorough seal of the entire system and protective cuspal coverage become the standard of practice.

The cornerstone of a successful coronal seal is the ability to obtain deep dentinal bonding. In addition to providing the coronal seal of the root canal system, deep dentinal bonding must also ensure the retention of the core. Each case needs to be individually assessed in this regard. In order to maximize deep dentinal bonding, a dual-cured bonding agent is recommended in conjunction with a dual-cured resin.[35] The typical sequence to attain maximum deep dentinal bonding is solvent, etchant, prebond, followed by the mixing of A and B. This older generation bonding agent has been shown to have increased bond strength when used in conjunction with a dual-cured resin due to the compatibility of the materials.[35]

BRINGING THIS SERIES TOGETHER CLINICALLY

Case 1

A patient presented with a distinctive lesion noted near tooth No. 12 (Figure 7a). Pulpal testing suggested the presence of a necrotic pulp of tooth No. 12. A CBCT image was taken for clos-

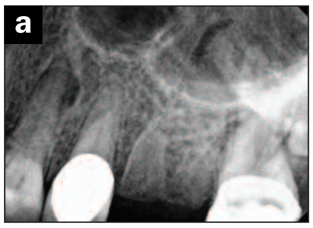

Figure 7a. Two-dimensional (2-D) digital periapical radiograph.

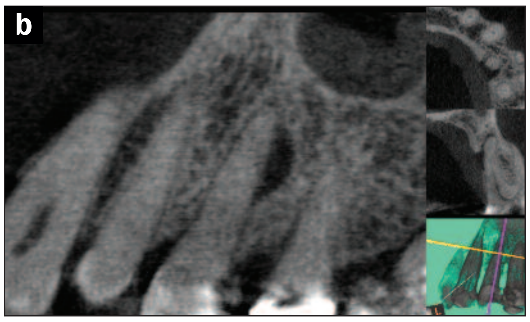

Figure 7b. Cone beam computed tomography (CBCT): Note the branching of the lateral canal into 2 portals of exit.

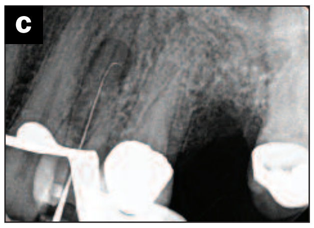

Figure 7c. File fed into the lateral pulpal branch.

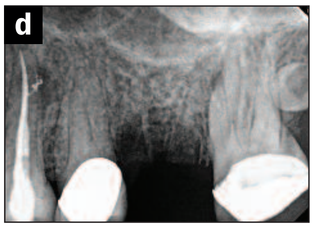

Figure 7d. Straight-on postoperative image. Note the branching of the lateral system leading to 2 portals of exit.

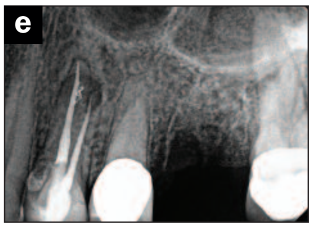

Figure 7e. Mesially angled postoperative image.

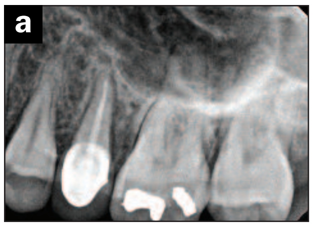

Figure 8a. Two-D digital periapical radiograph.

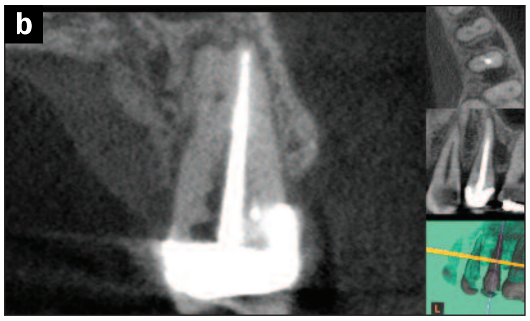

Figure 8b. CBCT: Note the apical split of the main canal into 2 root tips. Also note the lateral canal feeding the lateral lesion.

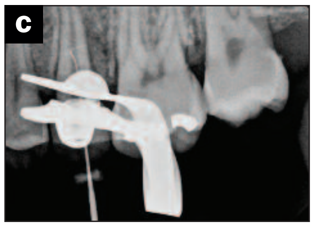

Figure 8c. Image documenting disassembly and a file in the lateral pulpal branch.

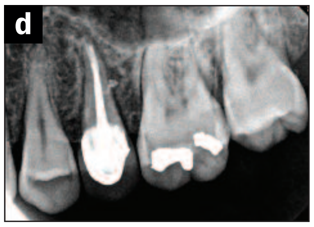

Figure 8d. Straight-on postoperative image.

Figure 8e. Mesially angled postoperative image.

er assessment of the pulpal anatomy and lesion present (Figure 7b). Upon CBCT examination, the lateral radiolucency was confirmed to be an extension of endodontic breakdown into the periradicular tissues through an accessory canal. In addition to aiding in the diagnosis of a lesion of endodontic origin, the information granted by the CBCT assisted in location and treatment of the mid-root lateral anatomy. There is value in remembering that periradicular radiolucencies will always have a central portal of exit from the pulpal system.[36,37] Figure 7c illustrates the negotiation of the pulpal branch exiting into the center of the radiographic lesion.

Direct instrumentation of infected pulpal systems holds significance as we know that direct instrumentation of infected pulpal systems facilitates disinfection.[38] In addition to directly engaging infected areas, disinfectants more readily move into areas upon the removal of instruments. As with all cases, once shaping was completed to its full potential, active disinfection was employed in an effort to increase levels of penetration of irrigants, such as the EndoVac (SybronEndo) and the EndoActivator (Manufactured by SybronEndo).[2] Again, postshaping active irrigation increases the efficacy of our irrigants.

The root canal system was then thoroughly dried and *corked* employing the above thermomechanical properties of gutta-percha (Figures 7d and 7e). It is appropriate to note here that sealer is well known for its role in assisting the adherence at the dentin-gutta-percha interface.[39] Immediately after the intricacies of the root system were sealed with warm vertical compaction of gutta-percha and sealer, a permanent coronal seal was accomplished with deep dentinal bonding, as discussed above.

Case 2

A patient presented for a second opinion related to root canal treatment that had been completed on tooth No. 13 a year earlier. The patient described having persistent sensitivity to localized chewing with episodes of pressure and swelling. Upon initial evaluation, a digital periapical radiograph was taken (Figure 8a). Although this 2-dimensional radiograph was diagnostic, CBCT evaluation was employed for closer assessment of the previous treatment and for better evaluation of periradicular breakdown (Figure 8b). In addition to better illustrating the extension of the endodontic disease within the attachment apparatus, the CBCT clearly revealed the untreated main and accessory canals. The patient was scheduled to have the disassembly and endodontic retreatment done during a live demonstration for the second year endodontic specialty residents from the University of Southern California and the University of California at Los Angeles. This hands-on course at Signature Specialists, showed how the use of CBCT guides treatment of complex pulpal anatomy. The live course was able to show the full potential of fluidly moving the 3-D images for visualization. This is something that cannot be illustrated in a 2-D presentation such as this article. The CBCT showed where and how the pulpal system branched in the apical third. It further allowed for focused efforts in navigating the infected mid-root lateral system (Figure 8c). Upon completion of the disassembly and shaping the root canal system, active disinfection was illustrated. After completely drying and *corking* the complex root canal system, deep dentinal bonding was placed to accomplish the coronal seal while this isolated pulpal system was at its highest level of disinfection (Figures 8d and 8e).

Figure 9. Live-patient demonstration as a part of the 2010 American Association of Endodontists' Master Clinician Series in San Diego, Calif. Dr. Simons presented the use of CBCT for endodontic evaluation, and illustrated its profound impact in guiding successful retreatment.

Live patient demonstrations allow for the clinical experience for all. This type of training brings the reality of what is being portrayed to the attendees in a practical setting. The American Association of Endodontists (AAE) has recognized this value. The AAE has implemented this type of live patient demonstration as the Master Clinican Series for its annual session (Figure 9).

CLOSING COMMENTS: FUTURE DIRECTIONS

Challenges created by the vast array of root canal system complexities speak as much to sealing all portals of exit as it does to the difficulty in shaping and disinfecting them. Therefore, as with the focus and advances in the realm of 3-D visualization, shaping, and disinfection, there comes the need to focus on improvements related to 3-D obturation. A technique that simplifies the sophistication of sealing such random complexities is needed for our collective success rates to reach closer to the 100% mark. Fortunately, recent efforts have been devoted to this well-established objective for success. A progressive technique that allows all practitioners to attain a consistent 3-D seal of the entire root canal system with a dense *cork* of gutta-percha is on the horizon. This new technique will be introduced and done live as part of the Master Clinician Series at the 2012 AAE Annual Session in Boston.

This 3-part series has highlighted some of the recent technological advances that have allowed us to be better equipped when facing endodontic challenges. It is an exciting and rewarding time to practice endodontics because of these improvements. These advances in our ability to visualize, disinfect, and seal the root canal system have enabled us to push limits of attainable and sustainable levels of success. Dr. Schilder advised that the success of our outcomes was 100 - x and that we are the X factor. He meant that successful outcomes are 100% minus our inability to attain well-established objectives for successful outcomes. Although we hold the responsibility to accomplish these objectives, innovative advances in endodontic treatment modalities will undoubtedly have an impact on our ability to attain them. Our efforts must remain steadfast and rooted in science for us to continue to evolve and close the gap in our pursuit of the highest levels of success. The future of our profession is in the hands of committed and skilled clinicians who will strive to reach optimal clinical and biologic outcomes. Progressive exploration into the areas discussed in this 3-part article series will help keep endodontic treatment at the forefront of available treatment options.✦

References

1. Simons W. Revolutionary Advances in Endodontics, Part 1: CBCT. *Dentistry Today.* 2011;30:96-102.
2. Simons W. Revolutionary Advances, Part 2: Active DIsinfection. *Dentistry Today*. 2011;30:88-93.
3. Ranade MP, Kamra AI. A comparative tissue toxicity evaluation of four endodontic materials. *Endodontology*. 2003;15:7-13.
4. Wu M-K, Fan B, Wesselink PR. Diminished leakage along root canals filled with gutta-percha without sealer over time: a laboratory study. *Int Endod J*. 2000;33:121-125.
5. Schilder H. Filling root canals in three dimensions. *Dent Clin North Am*. 1967 Nov;723-744.
6. Schilder H, Goodman A, Aldrich W. The thermomechanical properties of gutta-percha. I. The compressibility of gutta-percha. *Oral Surg Oral Med Oral Pathol*. 1974; 37:946-953.
7. Katz A, Kaffe I, Littner M, et al. Densitometric measurement of radiopacity of Gutta-percha cones and root dentin. *J Endod*. 2009;16:211-213.
8. Kaplowitz GJ. Evaluation of Gutta-percha solvents. *J Endod*. 1990;16:539-540.
9. Moorer WR, Genet JM. Antibacterial activity of gutta-percha cones attributed to the zinc oxide component. *Oral Surg Oral Med Oral Pathol*. 1982;53:508-517.
10. Obach E. *Cantor Lectures on Gutta-Percha*. London, England: William Trounce; 1898.
11. Seelingmann T, Torrithen GL, Faronnet H. *India Rubber and Gutta-Percha*. London, England: Scott Greenwood & Sons; 1910.
12. Tradescant J. *Museum Tradescantium: Or a Collection of Rareties Preserved at South Lambeth Near London*. London, England: John Grifmond; 1656.
13. Ferguson J. *All About Rubber and Gutta-Percha*. London, England: J Hadden & Co; 1899.
14. Cruse WP, Bellizzi R. A historic review of endodontics, 1689-1963, part 1. *J Endod*. 1980;6:495-499.
15. Cohen S, Burns RC. *Pathways of the Pulp*. 8th ed. St. Louis, MO: Mosby; 2002:293-295.
16. Grossman L. A brief history of endodontics. *J Endod*. 1982:8(suppl):S36-S40.
17. Hess W, Zürcher E, Dolamore WH. *Anatomy of the Root-Canals of the Teeth of the Permanent Dentition*. New York, NY: William Wood; 1925:3-49.
18. Dow PR, Ingle JI. Isotope determination of root canal failure. *Oral Surg Oral Med Oral Pathol*. 1955;8:1100-1104.
19. Schilder H, Goodman A, Aldrich W. The thermomechanical properties of gutta-percha. Part V. Volume changes in bulk gutta-percha as a function of temperature and its relationship to molecular phase transformation. *Oral Surg Oral Med Oral Pathol*. 1985;59:285-296.
20. Bunn CW. Molecular structure and rubber-like elasticity. I. The crystal structures of beta gutta-percha, rubber and polychloroprene. *R Soc Lond A*. 1942;180:40-66.
21. Schilder H, Goodman A, Aldrich W. The thermomechanical properties of gutta-percha. Part III. Determination of phase transition temperatures for gutta-percha. *Oral Surg Oral Med Oral Pathol*. 1974;38:109-114.
22. Goodman A, Schilder H, Aldrich W. The thermomechanical properties of gutta-percha. Part IV. A thermal profile of the warm gutta-percha packing procedure. *Oral Surg Oral Med Oral Pathol*. 1981;51:544-551.
23. Kakehashi S, Stanley HR, Fitzgerald RJ. The effects of surgical exposures of dental pulps in germfree and conventional laboratory rats. *J South Calif Dent Assoc*. 1966;34:449-451.
24. Möller AJ, Fabricius L, Dahlén G, et al. Influence on periapical tissues of indigenous oral bacteria and necrotic pulp tissue in monkeys. *Scand J Dent Res*. 1981;89:475-484.
25. Southard DW. Immediate core buildup of endodontically treated teeth: the rest of the seal. *Pract Periodontics Aesthet Dent*. 1999;11:519-526.
26. Tronstad L, Asbjørnsen K, Døving L, et al. Influence of coronal restorations on the periapical health of endodontically treated teeth. *Endod Dent Traumatol*. 2000;16:218-221.
27. Heling I, Gorfil C, Slutzky H, et al. Endodontic failure caused by inadequate restorative procedures: review and treatment recommendations. *J Prosthet Dent*. 2002;87:674-678.
28. Weine FS. *Endodontic Therapy*. 5th ed. St. Louis, MO: Mosby; 1996:4.
29. Ray HA, Trope M. Periapical status of endodontically treated teeth in relation to the technical quality of the root filling and the coronal restoration. *Int Endod J*. 1995;28:12-18.
30. Torabinejad M, Ung B, Kettering JD. In vitro bacterial penetration of coronally unsealed endodontically treated teeth. *J Endod*. 1990;16:566-569.
31. Alves J, Walton R, Drake D. Coronal leakage: endotoxin penetration from mixed bacterial communities through obturated, post-prepared root canals. *J Endod*. 1998;24:587-591.
32. Ricucci D, Gröndahl K, Bergenholtz G. Periapical status of root-filled teeth exposed to the oral environment by loss of restoration or caries. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2000;90:354-359.
33. Swanson K, Madison S. An evaluation of coronal microleakage in endodontically treated teeth. Part I. Time periods. *J Endod*. 1987;13:56-59.
34. Salehrabi R, Rotstein I. Endodontic treatment outcomes in a large patient population in the USA: an epidemiological study. *J Endod*. 2004;30:846-850.
35. Schwartz RS, Fransman R. Adhesive dentistry and endodontics: materials, clinical strategies and procedures for restoration of access cavities: a review. *J Endod*. 2005;31:151-165.
36. West JD. *The Relationship Between Three-Dimensional Endodontic Seal and Endodontic Failure* [master's thesis]. Boston, MA: Boston University; 1975.
37. Schilder H. Canal debridement and disinfection. In: Cohen S, Burns RC. *Pathways of the Pulp*. St. Louis, MO: Mosby; 1976:111-133.
38. Byström A, Sundqvist G. Bacteriologic evaluation of the efficacy of mechanical root canal instrumentation in endodontic therapy. *Scand J Dent Res*. 1981;89:321-328.
39. Marshall FJ, Massler M. The sealing of pulp less teeth evaluated with radioisotopes. *J Dent Med*. 1961;16:172-184.

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Disclosure: Dr. Simons reports no disclosures.

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