Root Canal Adhesive Filling in Dogs' Teeth with or without Coronal Restoration: A Histopathological Evaluation

Mario Roberto Leonardo, DDS, PhD, Frederick Barnett, DMD,† Gilberto J. Debelian, DMD, PhD,‡ Regina Karla de Pontes Lima, DDS,§ and Léa Assed Bezerra da Silva, DDS, PhD**

Abstract

The purpose of this study was to evaluate in vivo the response of the periradicular tissues after endodontic treatment and root filling with Epiphany/Resilon (Penntron Clinical Technologies, LLC, Wallingford, CT) or gutta percha and new Sealapex (SybronEndo, Glendora, CA) in dogs' teeth with or without coronal restoration. Teeth without coronal restorations were used to assess the influence of continuous exposure to the oral environment on the periradicular tissues. Sixty root canals with vital pulps in three dogs were instrumented and obturated in a single session and randomly assigned to one of four groups as follows. group 1: root canal filling with Epiphany/Resilon with coronal restoration, group 2: root canal filling with Sealapex sealer and gutta percha with restoration, group 3: root canal filling with Epiphany/Resilon without restoration, and group 4: root canal filling with Sealapex sealer and gutta percha without coronal restoration. After 90 days, the animals were euthanized, and the maxillas and mandibles were removed and submitted for histologic processing. Longitudinal sections were obtained and stained with hematoxylin and eosin, Mallory's trichrome, and Brown and Brenn stains and examined under light microscopy. There were significant differences found between the four groups ($p < 0.05$). The results showed that roots canals filled with Epiphany/Resilon, with coronal restoration, had significantly less periradicular inflammation than roots canals filled with gutta percha and Sealapex, with coronal restoration ($p = 0.021$). No significant difference was observed in the intensity of inflammation between roots canals filled with Epiphany/Resilon with no restoration and roots filled with gutta percha and Sealapex with restoration ($p = 0.269$). Roots canals filled with gutta percha and Sealapex sealer without coronal restoration showed the greatest degree of periradicular inflammation. *(J Endod 2007;33:1299–1303)*

Key Words

Coronal leakage, Resilon, root canal–filling materials, Sealapex

The role of bacteria and their byproducts in the development of pulp and periapical lesions has been well established (1). Therefore, the main goal of endodontic treatment is to prevent the ingress of or the elimination of microorganisms from the root canal system. Complete periradicular healing after root canal therapy may be influenced not only by the antimicrobial effectiveness of the debridement and disinfection procedure but also the apical limit of root canal obturation and the composition of the filling materials (2–5). Additionally, the quality of the coronal restoration in root-filled teeth has been considered to be an important etiologic factor in posttreatment endodontic disease (6–9). It has been well documented that gutta percha and sealer do not provide a dependable barrier against coronal leakage in in vitro studies (10–15).

Resilon (Penntron Clinical Technologies, LLC, Wallingford, CT), a synthetic, thermoplastic resin material has been recently introduced to the market. According to the manufacturer, the Resilon cones contain a blend of dimethacrylates and exhibit adhesion both to root dentin and to methacrylate-based sealers, such as Epiphany (Penntron Clinical Technologies, LLC, Wallingford, CT). The use of the Epiphany/Resilon system for root canal obturation, as compared with gutta percha with traditional sealers, has been claimed to reduce or prevent coronal microleakage, thus providing a superior seal (16–18). Although this claim has been challenged by other investigations, gutta percha was not shown to be superior material (19–21). Clinical outcome assessments have also been shown to be favorable with the use of Resilon/Epiphany (22, 23).

Thus, the Epiphany/Resilon system is a relatively new material for root canal obturation, and, to the best of our knowledge, only one study has investigated its biocompatibility in vivo (24). Therefore, the purpose of this study was to evaluate in vivo the periradicular tissue response after root canal filling with the Epiphany/Resilon system compared with a new formulation of a Sealapex (SybronEndo, Glendora, CA) and gutta percha in dogs' teeth with or without coronal restoration.

Materials and Methods

All animal procedures performed in this study conformed to the protocols reviewed and approved by the Ethics in Animal Research Committee of the São Paulo State University and were in compliance with the International Guiding Principles for Biomedical Research Involving Animals (Geneva, 1985). This study was based on the protocol recommended by the International Organization for Standardization (ISO 7405-1997 [E]: Biological evaluation of dental materials) (25).

A total of 60 root canals were available for study by using the second, third, and fourth mandibular premolars and the second and third maxillary premolars of 3 dogs. The animals were anesthetized intravenously with sodium thiopental (Thionembutal; Abbott Laboratories, São Paulo, Brazil; 30 mg/kg body weight), and standardized ra-

From the *Department of Pediatric Clinic, Preventive and Social Dentistry, School of Dentistry of Ribeirão Preto, University of São Paulo, Brazil; †Department of Endodontics, School of Dentistry, Temple University, Philadelphia, Pennsylvania; ‡Department of Endodontics and the Institute of Oral Biology, School of Dentistry, University of Oslo, Oslo, Norway; and §Department of Restorative Dentistry, School of Dentistry of Araraquara, State University of São Paulo, Araraquara, Brazil.

Address requests for reprints to Dr Léa Assed Bezerra da Silva, Departamento de Clinical Infantil, Odontologia Preventiva e Social, Faculdade de Odontologia de Ribeirão Preto-USP, Av. do Café, s/n Monte Alegre, 14040-904, Ribeirão Preto, SP, Brazil. E-mail address: lea@forp.usp.br.

0099-2399/$0 - see front matter

doi:10.1016/j.joen.2007.07.037

diographs were taken using custom-made film-holding devices. After isolation of the teeth with a rubber dam and disinfection of the operative field with 2% chlorhexidine gluconate, access to the pulp chambers were made. The working length was determined to be 2 mm short of the radiographic apex using size #30 K-files (Dentsply Maillefer Instruments, Ballaigues, Switzerland). The pulp tissue was extirpated, and the root canals were irrigated with 3.6 mL of 1.0% sodium hypochlorite solution.

The apical cementum layer was then perforated with the sequential use of size #15 to #30 K-files, thus creating standardized apical openings. Thereafter, the canals were instrumented to the working length up to a size #60 K-file (26) under irrigation with 1% sodium hypochlorite solution at each instrument change. A size #30 K-file was taken to the total root length to ensure apical patency. After final irrigation with sodium hypochlorite, the root canals were dried with sterile paper points and then filled with 14.3% buffered EDTA pH 7.4 (Odahcan-Herpo Produtos Dentários Ltda, Rio de Janeiro, Brazil) for 3 minutes. Sterile saline was used to rinse out the EDTA, and the canals were then dried with sterile paper points.

All materials were tested in each animal, and the experimental protocols were performed in alternate quadrants in a randomized manner. In group 1 (E/R-WR), 20 root canals were filled with Epiphany/Resilon according to the manufacturer's instructions using the lateral condensation technique with coronal restoration. In group 2 (GP-WR), 10 root canals were filled with gutta percha points (Dentsply-Herpo, Petrópolis, Brasil) and new Sealapex sealer using the lateral condensation technique with coronal restoration. In group 3 (E/R-NR), 20 root canals were filled with Epiphany/Resilon using the lateral condensation technique with no coronal restoration, and in group 4 (GP-NR), 10 root canals filled with gutta-percha points and new Sealapex sealer using the lateral condensation technique with no coronal restoration.

The coronal access cavities of groups 1 and 2 were restored with a glass ionomer cement base (Vitremer; 3M/ESPE, St Paul, MN) followed with silver amalgam (Velvalloy; SS White Ltd, Rio de Janeiro, Brazil). The coronal access cavities in groups 3 and 4 were not restored, and the filled root canals were left exposed to the oral environment.

The present study used the recently modified formulation of Sealapex root canal sealer, in which one of the major alterations was the replacement of the radiopacifier (ie, from barium sulfate to bismuth trioxide). The new Sealapex has a 2-year shelf life instead of the 1-year shelf life of the previous formulation.

After a 90-day ($\pm$5 days) experimental period, the animals were euthanized with a lethal intravenous overdose of sodium pentobarbital. The maxillas and mandibles were dissected and sectioned to obtain individual roots that were fixed in 10% buffered formalin for 72 hours, demineralized in EDTA, and embedded in paraffin. The specimens were serially sectioned, and longitudinal sections were stained with hematoxylin and eosin, Mallory's trichrome, and Brown and Brenn stains and examined under light microscopy by a skilled observer blinded to the treatment groups.

The histomorphological parameters used in this study (Table 1) were based on criteria previously described (27). The specimens were examined, and each parameter was scored 1 to 4 (with 1 being the best result and 4 being the most severe). The study-wide null hypothesis was that the distributions of histologic findings would be the same among the four experimental groups for all six histomorphological parameters. To protect the study-wide type I error rates, multigroup comparisons were performed by using a Bonferroni correction alpha of $p = 0.0083$. If any of the multigroup comparisons were significant at $p < 0.0083$, then unadjusted significance levels were used to determine which outcomes had distributions with significant differences. Thus, for each histomorphometric parameter, a null hypothesis of equal distributions among the four groups was tested by the Kruskal-Wallis nonparametric test. If p was <0.05 for differences between the four groups, then pair-wise Mann-Whitney rank sum tests were performed to identify which groups significantly differed from each other.

Results

The results obtained for all groups are seen in Table 2. There were significant differences found between the four groups ($p < 0.0083$). Therefore, the null hypothesis was rejected that there would be no significant differences between the four groups. There were two histomorphologic outcomes, intensity and extension of periradicular inflammation, in which multigroup comparisons reached significance greater than the Bonferroni correction values of $p < 0.0083$. Therefore, comparisons between groups for individual outcomes were performed as described previously. Representative photomicrographs from the vari-

TABLE 1. Parameters and Scores Used for Evaluation

Parameters	Scores
Extension of the inflammatory reaction	Absent (score 1) Restricted to the apical foramen (score 2) Up to half of the apical periodontal ligament (score 3) Beyond half the apical periodontal ligament (score 4)
Intensity of the inflammatory infiltrate	0 to 0.91 inflammatory cells (score 1) 0.92 to 5.90 inflammatory cells (score 2) 5.91 to 36.3 inflammatory cells (score 3) More than 36.3 inflammatory cells (score 4)
Periodontal ligament thickness (mm)	Normal (0.36 mm) (score 1) Moderately enlarged (0.37–046 mm) (score 2) Intensity enlarged (0.47–0.55 mm) (score 3) Severely enlarged (more than 0.56 mm) (score 4)
Mineralized tissue resorption	Absent (score 1) Present (score 2)
Apical limit of root canal filing	Slightly short of the foraminal opening (score 1) At the limit of the foraminal opening (score 2) Beyond the foraminal opening (score 3)
Apical opening sealed with mineralized tissue	Complete sealing (score 1) Sealing beyond half (score 2) Sealing up to half (score 3) Absence of sealing (score 4)

TABLE 2. Means of Histomorphological Scores per Group

Parameters/Materials	Scores	Res-WR group 1 (n = 18)	GP-WR group 2 (n = 10)	Res-NR group 3 (n = 18)	GP-NR group 4 (n = 10)
Intensity of the inflammatory infiltrate	0 to 0.91 inflammatory cells (score 1)	61.11	0.00	22.22	0.00
	0.92 to 5.90 inflammatory cells (score 2)	5.56	40.0	38.89	20.0
	5.91 to 36.3 inflammatory cells (score 3)	22.22	40.0	16.67	20.0
	More than 36.3 inflammatory cells (score 4)	11.11	20.0	22.22	60.0
Extension of the inflammatory reaction	Absent (score 1)	61.11	0.00	55.56	0.00
	Restrict to the apical foramen (score 2)	5.56	20.0	5.56	10.0
	Up to half of the apical periodontal ligament (score 3)	16.67	30.0	11.11	30.0
	Beyond half of the apical periodontal ligament (score 4)	16.67	50.0	27.78	60.0
Periodontal ligament thickness (mm)	Normal (0.36 mm) (score 1)	33.33	30.0	27.78	20.0
	Moderately enlarged (0.37–046 mm) (score 2)	33.33	20.0	22.22	30.0
	Intensely enlarged (0.47–0.55 mm) (score 3)	22.22	40.0	16.67	30.0
	Severely enlarged (more than 0.56 mm) (score 4)	11.11	10.0	33.33	20.0
Mineralized tissue resorption	Absence (score 1)	88.89	80.0	77.78	60.0
	Presence (score 2)	11.11	20.0	22.22	40.0
Apical limit of root canal filing	Slightly short of the apical opening (score 1)	66.67	60.0	50.0	40.0
	At the limit of the apical opening (score 2)	0.00	20.0	0.00	40.0
	Beyond the apical opening (score 3)	33.33	20.0	50.0	20.0
Apical opening sealed with mineralized tissue	Complete sealing (score 1)	22.22	10.0	5.56	0.00
	Sealing beyond half (score 2)	22.22	30.0	11.11	0.00
	Sealing up to half (score 3)	33.33	50.0	33.33	40.0
	Absence of sealing (score 4)	22.22	10.0	50.0	60.0

ous groups are seen in Figure 1. Two teeth from groups 1 and 3 were lost in processing.

Intensity of Periradicular Inflammation

There were significant differences observed between the four groups ($p = 0.004$). Group1 (E/R-WR) had the greatest number of roots (61.1%) without periradicular inflammation as well as the lowest ranked score for all groups, whereas group 4 (GP-NR) had the greatest intensity of inflammation of the four groups. For the two groups with coronal restorations (1 and 2), the group filled with Epiphany/Resilon had significantly less periradicular inflammation than did the gutta percha/Sealapex group ($p = 0.021$). Although the Epiphany/Reslion group with no restoration had a lower mean inflammation score than did the gutta percha/Sealapex group with restoration, this difference was not statistically different ($p = 0.27$). Group 1 (E/R-WR) had a lower mean group score of inflammation intensity than did group 3 (E/R-NR); however, this difference was not statistically significant ($p = 0.093$). For the two groups without coronal restorations, the Epiphany/Resilon roots had significantly less inflammation than the roots filled with gutta percha/Sealapex ($p = 0.021$).

Extension of the Inflammatory Reaction

The differences between the four groups were statistically significant ($p = 0.002$). Group 1 (E/R-WR) had the lowest mean score, followed by group 3 (E/R-NR), then group 2 (GP-WR), and then group 4 (GP-NR).

For the two groups with restorations, Epiphany/Resilon had significantly better scores than did gutta percha/Sealapex ($p = 0.005$). For the two groups with no coronal restorations, Epiphany/Resilon had significantly more favorable scores than did GP/Sealapex ($p = 0.012$). Roots filled with Epiphany/Resilon with no coronal restoration had significantly less extension of the inflammatory infiltrate than did the gutta percha/Sealapex roots with coronal restorations ($p = 0.025$).

Differences between the four groups that were not statistically significant at the multigroup level of $p < 0.0083$ were periodontal ligament thickness, apical limit of the root filling, apical foramina closure with hard tissue, or mineralized tissue resorption.

Discussion

Although the dog is considered to be an excellent experimental animal model, dogs' teeth terminate with an apical delta comprised of numerous canal ramifications. This apical anatomy is quite different than that of humans, and it is possible that periradicular tissue reactions could be different as well. To compensate for this anatomic difference, the apical cementum layer was mechanically perforated at the anatomic apex by using sterile K-files, and apical patency was maintained throughout the instrumentation procedure (3–5, 27). In creating such a standardized apical opening, we attempted to create an apical complex as close as possible to that of a human tooth. Because significant differences were found between the four experimental groups, it would appear that creating standardized apical openings allowed for differences to be observed.

It is accepted that gutta percha combined with traditional root canal sealers do not prevent the coronal-to-apical migration of bacteria and/or their byproducts when challenged (10–18, 20–21). This flow of noxious stimuli may ultimately lead to periapical disease (6–9, 12, 16, 28). Of course, gutta percha with traditional sealers has been associated with successful endodontic outcomes when thorough debridement and disinfection of the root canal system is followed by the placement of a "proper" coronal restoration (2, 6–9). However, endodontic root fillings should serve three principle functions: entombing most of the surviving bacteria that remain within the root canal system (fins, isthmuses, and dentinal tubules); preventing the influx of periapical-derived tissue fluid from reaching the surviving bacteria within the root canal system; and acting as a coronal seal or barrier, thereby preventing

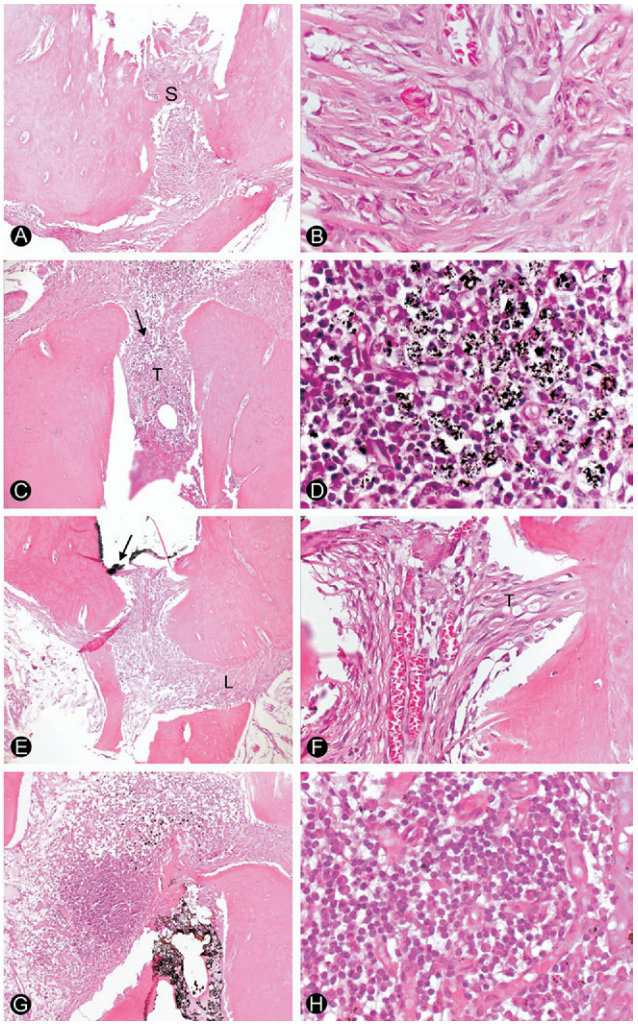

Figure 1. (*A*) Group 1: complete closure of the apical opening with mineralized tissue (S). Interstitial tissue (T) ingrowth into the apical opening (hematoxylin and eosin, original magnification ×40). (*B*) Higher magnification of the same specimen in *A* showing large number of fibers in different directions, cells, and vessels (hematoxylin and eosin, original magnification ×80). (*C*) Group 2: the absence of apical closure with interstitial tissue (T). Filling material (arrow) within the matrix (hematoxylin and eosin, original magnification ×40). (*D*) Higher magnification of the same specimen in *C* showing filling material within the matrix and severe intensity of inflammatory cells. (hematoxylin and eosin, original magnification ×60). (*E*) Group 3: the absence of apical closure close to the filling material (arrow). Mildly altered periodontal ligament (L). (hematoxylin and eosin, original magnification ×40). (*F*) Higher magnification of the same specimen in *E* showing normal interstitial tissue with intense formation of collagen fibers (hematoxylin and eosin, original magnification ×60). (*G*) Group 4: root apex view. Absence of apical closure with mineralized tissue. Moderately enlarged periodontal ligament showing a severe inflammatory cell focus close to the filling material (original magnification ×40). (*H*) Detail of the same specimen in *G*. Concentrated inflammatory infiltrate, areas of edema, and absence of fibers (hematoxylin and eosin, original magnification ×64).

re-infection of the root canal system from the oral cavity. It appears that the present materials are less than ideal in all three requirements (10–21). In this regard, root fillings containing gutta percha and sealer may be considered the "weak link" in endodontics (10–21). The importance of a "good" coronal seal on periapical health after endodontic treatment has been previously demonstrated (6–9). More recently, Tay et al (19) highlighted the importance of the coronal seal after endodontic treatment; their study showed "that the creation of a consistent hermetic apical seal in the apical 4mm of the root canal was not realized for either material (Resilon or gutta-percha/AH-Plus)." However, this result must be questioned regarding the importance of establishing an adequate apical seal and achieving clinical endodontic success. In contrast, Patel et al (29) used confocal microscopy that allowed visualization of sealer penetration within dentinal tubules of root-filled teeth without resorting to specimen preparation techniques that might create artifacts. Their study compared the penetration depth into dentinal tubules of Epiphany/Resilon sealer to that of Tubliseal (a zinc oxide-eugenol– based sealer) after root filling. Their results showed that within each third of the canal the penetration of Epiphany/Resilon was significantly greater than that of Tubliseal ($p < 0.05$).

This study may be looked at as having two distinct components: (1) biocompatibility or tissue reactions to the root-filling materials, Epiphany/Resilon or Sealapex/gutta percha, using the results from the teeth with coronal restorations (groups 1 and 2) and (2) sealing ability of Epiphany/Resilon or Sealapex/gutta percha using the results of Groups 3 and 4 (teeth with no coronal restorations). Of course, groups 3 and 4 represent a worst-case clinical situation, in that coronal restorations were never placed and the root-filling materials were exposed to the oral environment for the entire length of the study.

Teeth With Coronal Restoration (Groups 1 and 2)

As to the intensity of the inflammatory infiltrate, the Epiphany/Resilon system had 61.1% score 1 (no inflammation) as compared with new Sealapex/gutta percha that had no roots scored as 1. Our results also showed 60% of roots with scores 3 and 4 using the new formulation of Sealapex. This is in contrast to previous studies (3–5) in which a satisfactory biocompatibility was found with the original composition of Sealapex sealer. The present study used the recently modified formulation of Sealapex root canal sealer, which has a 2-year shelf life instead of the 1-year shelf life of the previous formulation. One of the major alterations in Sealapex was the replacement of the radiopacifier (ie, from barium sulfate to bismuth trioxide). The differences between our results and those of previous studies (3–5) may suggest that this and other alterations in the original formulation might have negatively affected its biocompatibility. As such, additional studies should be performed.

Because the Epiphany/Resilon system has been recently introduced to the market, to the best of our knowledge, there is only one published study evaluating its intraosseous biocompatibility (24). According to the criteria used in that study, the Epiphany root canal sealer was the only material that showed favorable intraosseous biocompatibility within the two periods analyzed. In our study, it was observed that the teeth filled with Epiphany/Resilon had the most favorable periradicular tissue reactions in the intensity and extension of inflammation categories. When the apical limit of obturation was slightly short of the apical opening, deposition of mineralized tissue occurred in 22% of the cases. The histopathological results clearly showed that the teeth filled with Epiphany/Resilon system yielded better periapical tissue reactions than those of the new Sealapex even in overfilled root canals. It must be emphasized that these results were observed within a 90-day (±5) period.

Teeth Without Coronal Restoration (Groups 3 and 4)

The root canals filled with the new Sealapex sealer that remained exposed to the oral environment presented the worst results (ie, the greatest degree of intensity and extension of the inflammatory infiltrate as well as the largest number of cases with absence of complete sealing of the apical opening with mineralized tissue). These findings indicate that the coronal-to-apical infiltration was influenced by the composition of root canal–filling material.

The more favorable tissue reactions observed in the groups root filled wih Epiphany/Resilon compared with Sealapex sealer and gutta percha within the experimental period suggests a significantly greater sealing ability of Epiphany/Resilon material within the root canal system (15–18, 29). These findings are consistent with those of Shipper et al (16) who investigated the occurrence of apical periodontitis in vivo (dogs) secondary to coronal microbial inoculation of root canals filled with AH-26 sealer plus gutta percha or Epiphany/Resilon. Mild inflammation was observed in 82% of the root canals filled with AH-26 sealer plus gutta percha and in 19% of the canals filled with Epiphany/Resilon.

Therefore, the results of group 4 (root canal filling with the new Sealapex and gutta percha without coronal restoration) suggest that the sealing ability of this material was severely influenced by coronal exposure to the oral environment. This very poor in vivo result corresponds to many in vitro studies (10–15, 20, 21).

According to the results of this study, the Epiphany/Resilon system resulted in significantly more favorable periradicular tissue reactions than did roots filled with gutta percha and Sealapex, with or without coronal restorations. As such, under the conditions of this study, it appears that the Epiphany/Resilon system provided for better sealing of the root canal system in vivo than did gutta percha and Sealapex sealer. This study also showed the importance of the coronal restoration in preventing unfavorable periradicular tissue reactions.

References

1. Kakehashi S, Stanley HR, Fitzgerald RJ. The effect of surgical exposures of dental pulps in germ-free and conventional laboratory rats. Oral Surg 1965;20:340–4.
2. Sjogren U, Figdor D, Persson S, Sundqvist G. Influence of infection at the time of root filling on the outcome of endodontic treatment of teeth with apical periodontitis. Int Endod J 1997;30:297–306.
3. Holland R, Souza V. Ability of a new calcium hydroxide root canal filling material to induce hard tissue formation. J Endod 1985;11:535–43.
4. Leonardo MR, Silva LAB, Assed S, Ether SS. Calcium hydroxide root canal sealers - histopathologic evaluation of apical and periapical repair after endodontic treatment. J Endod 1997;27:428–32.
5. Silva LAB, Leonardo MR, Faccioli LH, Figueiredo F. Inflammatory response to calcium hydroxide based root canal sealers. J Endod 1997;23:86–90.
6. 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;28:12–8.
7. Tronstad L, Asbjornsen K, Doving L, Pedersen I, Eriksen HM. Influence of coronal restorations on the periapical health of endodontically treated teeth. Endod Dent Traumatol 2000;16:218–21.
8. Hommez GM, Coppens CR, De Moor RJ. Periapical health related to the quality of coronal restorations and root fillings. Int Endod J 2002;35:680–9.
9. Siqueira JF, Rocas IN, Alves FR, Campos LC. Periradicular status related to the quality of coronal restorations and root fillings in a Brazilian population. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2005;100:369–74.
10. Madison S, Swanson K, Chiles SA. An evaluation of coronal microleakage in endodontically treated teeth. Part II. Sealer types. J Endod 1987;13:109–12.
11. Pisano DM, DiFiore PM, McClanahan SB, Lautenschlager EP, Duncan JL. Intraorifice sealing of gutta-percha obturated root canals to prevent coronal microleakage. J Endod 1998;24:659–62.
12. Friedman S, Komorowski R, Maillet W, et al. In vivo resistance of coronally induced bacterial ingress by an experimental glass ionomer cement root canal sealer. J Endod 2000;26:1–5.
13. Timpawat S, Amornchat C, Trisuwan W. Bacterial coronal leakage after obturation with three root canal sealers. J Endod 2001;27:36–9.
14. De Moor RJ, Hommez GM. The long-term sealing ability of an epoxy resin root canal sealer used with five gutta percha obturation techniques. Int Endod J 2002;35:275–82.
15. Shipper G, Orstavik D, Teixeira FB, Trope M. An evaluation of microbial leakage in roots filled with a thermoplastic synthetic polymer-based root canal filling material (Resilon). J Endod 2004;30:342–7.
16. Shipper G, Teixeira FB, Arnold RR, Trope M. Periapical inflammation after coronal microbial inoculation of dog roots filled with gutta-percha or Resilon. J Endod 2005;31:91–6.
17. Tunga U, Bodrumlu E. Assessment of the sealing ability of a new root canal obturation material. J Endod 2006;32:876–8.
18. Stratton RK, Apicella MJ, Mines P. A fluid filtration comparison of gutta-percha versus Resilon, a new soft resin endodontic obturation system. J Endod 2006;32:642–5.
19. Tay FR, Loushine RJ, Weller N, et al. Ultrastructural evaluation of the apical seal in roots filled with a polycaprolactone-based root canal filling material. J Endod 2005;31:514–9.
20. Shemesh H, Wu MK, Wesselink PR. Leakage along root fillings with and without smear layer using two different leakage models; a two month longitudinal ex vivo study. Int Endod J 2006;39:968–76.
21. Baumgartner G, Zehnder M, Paqua F. Enterococcus faecalis type strain leakage through root canals filled with gutta-percha/AH plus or Resilon/Epiphany. J Endod 2007;33:45–7.
22. Debelian GJ. Treatment outcome of teeth treated with an evidenced-based disinfection protocol and filled with resilon. J Endod 2006;32:251 (abstr OR72).
23. Conner DA, Teixeira FB, Caplan DJ, Trope M. One year radiographic evaluation of teeth treated endodontically with Resilon root filling. J Endod 2006;32:254 (abstr PR7).
24. Sousa CJA, Montes CRM, Pascon EA, Loyola AM, Versiani MA. Comparison of intraosseous biocompatibility of AH Plus, Endo REZ, and Epiphany root canal sealers. J Endod 2006;656:62–7.
25. Dentistry—Preclinical evaluation of biocompatibility of medical devices used in dentistry—Test methods for dental materials. Geneva, Switzerland: International Standards Organization, 1997; ISO 7405.
26. Leonardo MR. Endodoncia: Tratamiento de conductos radiculares (Princípios Técnicos y Biologicos). Ed 4. São Paulo: Artes Médicas; 2005.
27. Holland R, Santana Junior A, Souza V, et al. Influence of apical patency and filling material on healing process of dog's teeth with vital pulp after root canal therapy. Braz Dent J 2005;16:9–16.
28. Yamauchi S, Shipper G, Buttke T, Yamauchi M, Trope M. Effect of orifice plugs on periapical inflammation in dogs. J Endod 2006;32:524–6.
29. Patel DV, Sherriff M, Ford TRP, Watson TF, Mannocci F. The penetration of RealSeal primer and Tubliseal into root canal dentinal tubules: a confocal microscopic study. J Endod 2007;40:67–71.