Effect of Smear Layer on Sealing Ability of Canal Obturation: A Systematic Review and Meta-analysis

Arash Shahravan, DDS, MSc, Ali-Akbar Haghdoost, MD, PhD,† Alireza Adl, DDS, MSc,* Hessam Rahimi, DDS,‡ and Fahimeh Shadifar, DDS§*

Abstract

The purpose of this systematic review was to determine whether smear layer removal reduces leakage of obturated human teeth in vitro. PubMed was searched for articles published between 1975 and 2005, and results were categorized based on the method of leakage test. Among 26 eligible papers with 65 comparisons, 53.8% of the comparisons reported no significant difference, 41.5% reported a difference in favor of removing the smear layer, and 4.7% reported a difference in favor of keeping it; differences were significant ($p < 0.001$). Of the 65 comparisons, 44 used the dye leakage test for evaluation. The combined effect in this group showed smear layer removal decreases dye leakage (z-score = 0.37, $z = 2.31$, $p = 0.021$). According to meta-regression, obturation type, test site and duration, sealer and dye, and publication year had no effect on the results. Under the conditions of these in vitro leakage studies, it is concluded that smear layer removal improves the fluid-tight seal of the root canal system whereas other factors such as the obturation technique or the sealer, did not produce significant effects. *(J Endod 2007;33:96–105)*

Key Words

Canal seal, meta-analysis, obturation, smear layer, systematic review

From the *Department of Endodontics, Kerman School of Dentistry, Kerman, Iran; the †Physiology Research Center, Kerman University of Medical Sciences, Kerman, Iran; the ‡Basic Sciences Research Department, Iran Center for Dental Research, Tehran, Iran; and §private practice, Kerman, Iran.

Address requests for reprints to H. Rahimi, DDS, 1441 Armacost Avenue, Apartment 5, Los Angeles, CA 90025-2230. E-mail address: hesamrahimi@gmail.com.

0099-2399/$0 - see front matter

doi:10.1016/j.joen.2006.10.007

Although the smear layer was first identified and introduced 30 years ago (1), the question of keeping it during canal treatment is still in debate. It has been suggested by some authors that keeping the smear layer may block the dentinal tubules and limit bacterial or toxin penetration by altering the dentinal permeability (2–4). In contrast, some experts believe that the smear layer must be completely removed from the surface of the canal wall because it can harbor bacteria and can be detrimental to effective disinfection of dentinal tubules by preventing sodium hypochlorite, calcium hydroxide, and other intracanal medicaments from penetrating into the dentinal tubules; and it can act as a barrier between obturating materials and the canal wall and thus interfere with the formation of an appropriate seal (5–10).

It is known that one of the most important factors strongly affecting the prognosis of a root canal treatment is the canal seal, gained by appropriate obturation (11). Although a great deal of effort has been made to understand the effect of the smear layer on the apical or coronal seal (9, 12–36), the controversy of keeping or removing it still exists; thus, a systematic review to find the answer to this question seems necessary. In addition, our knowledge about the interactions between the smear layer and factors such as obturation technique and sealer type is very limited. Moreover, the methodology of studies, type and site of leakage tests, and the sample size should be taken into account, in our judgment.

Because of the aforementioned reasons, the purpose of this study was to systematically review the literature to determine whether smear layer removal reduces leakage of extracted human teeth obturated with gutta-percha with different sealers in vitro.

Materials and Methods

A comprehensive search was initiated to identify studies on the subject published in English from January 1975 to January 2005, using the PubMed service of the National Library of Medicine and the U.S. National Institutes of Health. Different combinations of the following key words were used in search queries: endodontics, smear layer, leakage, and root canal. Using this method, 145 abstracts were primarily selected for review (Table 1).

The inclusion criteria were (a) relevance of the contents to the subject of this review (for example, the article of Arisu et al. (37) was among the primarily selected articles that were considered irrelevant, because it actually reported the effects of a type of laser on the morphology and permeability of apical dentin surfaces, which is not related to our research, and the article of Ozturk (41) was considered irrelevant because it evaluated the effects of dentinal adhesive systems on pulp chamber seal); (b) availability of the full-text version of the abstract; (c) presentation of experimental research; (d) use of extracted human teeth as samples; (e) use of gutta-percha as the obturating material; (f) inclusion of two groups in the research design, one group with smear layer and the other without it; and (g) presentation of data reporting a valid mean and standard deviation (SD).

Considering these criteria, 98 papers were excluded from the study, and 47 articles were selected, photocopied, and reviewed by two endodontists. The reference section of each of these articles then was studied to determine whether any of the references cited in the article matched our search criteria. The ones that matched were placed on a master list, and each time a reference section was reviewed, the references were checked against the master list. If the article did not appear on the master list, it was then located, reviewed, and cross-referenced. This exhaustive process of locating,

TABLE 1. Research articles primarily reviewed in this meta-analysis

No.	Author (ref. no.)	Year	Inclusion Criteria Met	Test Type
1	Arisu et al. (37)	2004	No	—
2	Behr et al. (38)	2004	No	—
3	Carrotte (39)	2004	No	—
4	Cobankara et al. (21)	2004	Yes	Fluid filtration
5	Economides et al. (12)	2004	Yes	Fluid filtration
6	Karadag et al. (40)	2004	No	—
7	Ozturk et al. (41)	2004	No	—
8	Park et al. (31)	2004	Yes	Dye leakage
9	Prati et al. (42)	2004	No	—
10	Sevimay et al. (43)	2004	No	—
11	Clark-Holke et al. (22)	2003	Yes	Bacterial penetration
12	Davis et al. (44)	2003	No	—
13	Ferrari and Tay (45)	2003	No	—
14	Hossain et al. (46)	2003	No	—
15	Al-Turki and Akpata (47)	2002	No	—
16	De la Macorra and Escribano (48)	2002	No	—
17	Moodley and Grobler (49)	2002	No	—
18	Murray et al. (50)	2002	No	—
19	Shigetani et al. (51)	2002	No	—
20	Tay et al. (52)	2002	No	—
21	Tay et al. (53)	2002	No	—
22	Tay et al. (54)	2002	No	—
23	Torabinejad et al. (55)	2002	No	—
24	Wimonchit et al. (56)	2002	No	—
25	Yang and Bae (5)	2002	No	—
26	Cox et al. (57)	2001	No	—
27	Gilbert et al. (58)	2001	No	—
28	Gilhooly et al. (59)	2001	No	—
29	Kubo et al. (60)	2001	No	—
30	Ozok et al. (61)	2001	No	—
31	Timpawat et al. (20)	2001	Yes	Fluid filtration
32	Al-Dewani et al. (62)	2000	No	—
33	Al-Dewani et al. (63)	2000	No	—
34	Ferrari et al. (64)	2000	No	—
35	Von Fraunhofer et al. (34)	2000	Yes	Electrochemical
36	Froes et al. (23)	2000	Yes	Dye leakage
37	Goya et al. (33)	2000	No	Dye leakage
38	Al-Jazairy and Louka (65)	1999	No	—
39	Davalou et al. (66)	1999	No	—
40	Economides et al. (19)	1999	Yes	Electrochemical
41	Kimura et al. (67)	1999	No	—
42	Kytridou et al. (68)	1999	No	—
43	Mannocci et al. (69)	1999	No	—
44	Yamazaki et al. (70)	1999	No	—
45	Barkhordar and Russel (71)	1998	No	—
46	Caliskan et al. (72)	1998	No	—
47	Santini (73)	1998	No	—
48	Sen and Buyukyilmaz (74)	1998	No	—
49	Timpawat and Sripanaratanakul (29)	1998	Yes	Dye leakage
50	Wu et al. (75)	1998	No	—
51	Youngson et al. (76)	1998	No	—
52	Pashley and Carvalho (77)	1997	No	—
53	Saunders and Saunders (78)	1997	No	—
54	Taylor et al. (18)	1997	Yes	Dye leakage
55	Behrend et al. (25)	1996	Yes	Bacterial penetration
56	Brannstrom (79)	1996	No	—
57	Chailertvanitkul et al. (24)	1996	Yes	Bacterial penetration
58	Leonard et al. (80)	1996	No	—
59	Meiers and Kresin (81)	1996	No	—
60	Perez et al. (82)	1996	No	—
61	Sen et al. (83)	1996	No	—
62	Vassiliadis et al. (16)	1996	Yes	Dye leakage
63	Zoellner et al. (84)	1996	No	—
64	Yap et al. (85)	1996	No	—
65	Goldberg et al. (26)	1995	Yes	Dye leakage
66	Hasegawa et al. (86)	1995	No	—
67	Lioyd et al. (30)	1995	No	Dye leakage
68	Sen et al. (87)	1995	No	—
69	Sultan and Pitt Ford (88)	1995	No	—
70	Trowbridge (89)	1995	No	—
71	Chigira et al. (90)	1994	No	—
72	De Gee et al. (91)	1994	No	—
73	Gaintanzopoulou et al. (92)	1994	No	—
74	Karagoz-Kucukay and Bayirli (17)	1994	Yes	Electrochemical

TABLE 1. (Continued)

No.	Author (ref. no.)	Year	Inclusion Criteria Met	Test Type
75	Prati (93)	1994	No	—
76	Saunders and Saunders (28)	1994	Yes	Dye leakage
77	Sim and Sidhu (94)	1994	No	—
78	Soh and Sidhu (95)	1994	No	—
79	Suzuki et al. (96)	1994	No	—
80	Tay et al. (97)	1994	No	—
81	Tidswell et al. (27)	1994	Yes	Dye leakage
82	Yap et al. (98)	1994	No	—
83	Cox (99)	1994	No	—
84	Barkmeier et al. (100)	1993	No	—
85	Duke (101)	1993	No	—
86	Ferrari et al. (102)	1993	No	—
87	Gencoglu et al. (15)	1993	Yes	Dye leakage
88	Mixson et al. (103)	1993	No	—
89	Yu et al. (104)	1993	No	—
90	Bakland (105)	1992	No	—
91	Barkmeier and Cooley (106)	1992	No	—
92	Brannstrom et al. (107)	1992	No	—
93	Cox (108)	1992	No	—
94	Jordan and Suzuki (109)	1992	No	—
95	Pashley (110)	1992	No	—
96	Prati et al. (111)	1992	No	—
97	Retief et al. (112)	1992	No	—
98	Saunders and Saunders (14)	1992	Yes	Dye leakage
99	Scherer et al. (113)	1992	No	—
100	Lumley et al. (114)	1992	No	—
101	Stabholz et al. (115)	1992	No	—
102	Swift and LeValley (116)	1992	No	—
103	Watson et al. (117)	1992	No	—
104	Wieczkowski et al. (118)	1992	No	—
105	Woody and Davis (119)	1992	No	—
106	Yu et al. (120)	1992	No	—
107	Abbott et al. (121)	1991	No	—
108	Gettleman et al. (122)	1991	No	—
109	Pashley (123)	1991	No	—
110	Pashley and Pashley (124)	1991	No	—
111	Richardson et al. (125)	1991	No	—
112	Watson et al. (126)	1991	No	—
113	White and Goodis (127)	1991	No	—
114	Yu et al. (128)	1991	No	—
115	Zidan et al. (129)	1991	No	—
116	Barkmeier et al. (130)	1990	No	—
117	Czonstkowsky et al. (131)	1990	No	—
118	Greene et al. (132)	1990	No	—
119	Pashley (133)	1990	No	—
120	Safavi et al. (4)	1990	No	—
121	Tjan and Dunn (134)	1990	No	—
122	Wendt et al. (135)	1990	No	—
123	Barkmeier et al. (136)	1989	No	—
124	Barkmeier and Cooley (137)	1989	No	—
125	Douglas (138)	1989	No	—
126	Srisawaski et al. (139)	1988	No	—
127	Cergneux et al. (140)	1987	Yes	Dye leakage
128	Evans and Simon (13)	1986	Yes	Dye leakage
129	Jodaikin et al. (141)	1986	No	—
130	Kennedy et al. (32)	1986	Yes	Dye leakage
131	Pashley and Depew (142)	1986	No	—
132	Goldberg et al. (36)	1985	Yes	Bacterial penetration
133	Pashley (143)	1985	No	—
134	Williams and Goldman (144)	1985	No	—
135	Brannstrom (145)	1984	No	—
136	Madison and Krell (35)	1984	Yes	Dye leakage
137	White et al. (10)	1984	No	—
138	Yamada et al. (146)	1983	No	—
139	Jodaikin and Austin (147)	1981	No	—
140	Pashley et al. (3)	1981	No	—
141	Michelich et al. (2)	1980	No	—
142	Wayman et al. (148)	1979	No	—
143	Goldberg and Abramovich (149)	1977	No	—
144	Lester and Boyde (8)	1977	No	—
145	McComb and Smith (1)	1975	No	—

Inclusion criteria: (a) relevance of the contents to the subject of this review; (b) availability of the full-text version of the abstract; (c) presentation of experimental research; (d) use of extracted human teeth as samples; (e) use of gutta-percha as the obturating material; (f) inclusion of two groups in the research design, one group with the smear layer and the other without it; and (g) presentation of data reporting a valid mean and standard deviation. Among those that met the inclusion criteria, the ones that used the dye leakage test participated in the final meta-analysis.

evaluating, and cross-referencing the articles was continued until there were no longer any new articles that could be added to the master list. Because all of the selected articles reported research performed on extracted human teeth and their methodology was simple, they were assessed as valid, and none of them were excluded from the review.

At the end, 26 articles published in English from 1975 to 2005, reporting the effects of smear layer removal on leakage of human extracted teeth obturated with gutta-percha were selected as the final candidates for systematic review. A database was then created and the following information was entered for each of the selected papers: author names, publication year, number of experimental groups, sample size, site of leakage test, type of leakage test, obturation technique, sealer type, results (mean and SD for quantitative data and percentage for qualitative data), and statistical significance (p value). If more than one comparison was performed in an article, the data were split into separate records in the database. Therefore, 65 comparisons were finally entered into the database (Table 2).

Statistical analysis was performed using Stata software version 8.0 (StataCorp LP, College Station, Texas). The level of significance was set at 0.05. The number of comparisons reporting nonsignificant or significant differences in favor or against smear layer removal was compared using the χ^2 test. The records then were divided into five groups based on the type of leakage test and further analysis was performed within each group. These groups were (a) dye leakage test (44 comparisons); (b) fluid filtration test (7 comparisons); (c) electrochemical test (7 comparisons); (d) bacterial leakage test (6 comparisons); and (e) volumetric dye leakage test (1 comparison).

Having checked the heterogeneity between study results, a fixed or random-effect meta-analysis model was used to estimate the combined effect. To assess the effect of differences in the methodology of the records, meta-regression was used, and the between-study variation was estimated by the restricted likelihood method. The findings of these studies were illustrated by Forest plot, and the potential risk of publication bias was assessed using Begg's adjusted rank correlation test.

Results

Among the 65 comparisons entered into the database, 35 (53.8%) reported no significant difference between removing or keeping the smear layer during canal preparation of extracted human teeth; 27 (41.5%) reported a significant difference in favor of removing the smear layer and 3 (4.7%) found a significant difference in favor of keeping the smear layer (Table 3). Comparing these numbers using the χ^2 test showed a significant difference ($p < 0.001$).

The comparison of these percentages with subcategories for main factors such as type and site of leakage test, type of obturation and sealer used, and the year of publication revealed similar patterns ($p > 0.05$), except for the sample size; studies with a large number of samples showed stronger evidence in favor of removing the smear layer ($p < 0.046$).

The methodology of these papers had considerable differences, particularly in the method used to measure the amount of leakage. Because of these differences, the studies were categorized into five groups and each group was analyzed separately, as follows:

Dye Leakage Test Studies

Among 44 comparisons, the results of two papers with 4 comparisons, Lloyd et al. (30) and Goya et al. (33) were not included in the meta-analysis process, because they did not report a valid mean and standard deviation. In addition, one of the comparisons of the Evans and Simon (13) article reported a zero mean and SD, which was automatically excluded from the calculations. Thus, 39 comparisons from this group actually participated in the meta-analysis process. Also, Taylor et al. (18) did not report a SD, and we used the reported mean and the coefficient of variance of other papers to estimate its SD.

The estimated rank of correlation coefficient of Begg's test was 0.3 ($p = 0.403$), which implies that there is no evidence for considerable publication bias in this study (Fig. 1).

The combined effect showed that removing the smear layer decreases dye leakage (z-score of difference = 0.37, $p = 0.021$) (Fig. 2).

The maximum and minimum effects were observed in Saunders and Saunders (28) (z-score = 2.0) and Froes et al. (23) (z-score = 1.35) papers. Nonetheless, this variation in the effect of removing the smear layer was not statistically significant ($q = 15.5$, $df = 38$, $p = 0.98$), meaning that there was no significance heterogeneity among the results of the studies.

Using meta-regression, we found that obturation type, site of leakage test, sealer type, type of dye used, duration of leakage test, and year of publication did not have a significant impact on the results and effects of the smear layer removal (Table 4).

Two types of ink were used in the observed studies: India ink and methylene blue. Although the type of dye and the test duration did not have any effect on the results of smear layer removal, the mean distance of penetration into the canal was 2.1 mm more for methylene blue than for India ink ($z = 3.4$, $p = 0.001$). In addition, after excluding the two studies that had used a centrifuge to accelerate the dye penetration process (9, 13), the results of meta-regression showed that a 1-day increase in test duration caused an average 0.3-mm increase in the dye penetration distance ($z = 2.15$, $p = 0.03$).

Fluid Filtration Test Studies

Seven of 65 comparisons used the fluid filtration test to assess the effects of smear layer removal. Because of variations in test duration, the reported statistics were so different that it was not possible to combine the results of these studies. However, 4 of 7 comparisons of this group showed a significant difference in favor of removing the smear layer and 1 showed a significant difference in favor of keeping it (Table 1).

Electrochemical Test Studies

In 7 of 65 comparisons, the electrochemical test was used to evaluate the effects of smear layer removal; however, as different techniques were applied in these studies, it was not possible to combine their results. Therefore, the effects of smear layer removal were assessed using the same method as for the previous group (6 comparisons showed results in favor of removing the smear layer, and 0 showed significant results in favor of keeping it).

Bacterial Leakage Test Studies

In 6 of 65 comparisons, the bacterial leakage test was used to evaluate the effects of smear layer removal; because of great variations, it was not possible to combine their results. Two comparisons reported a significant difference in favor of smear layer removal; none suggested keeping it.

Volumetric Dye Leakage

Only one study used this method to assess the effects of smear layer removal. Its results showed a significant difference in favor of smear layer removal.

Discussion

Among the 26 reviewed articles, 44 comparisons used the dye leakage test. Exploration of the p-values of these selected comparisons indicated that most of them had suggested removing the smear layer, leaving a small percentage supporting the idea of keeping it. The combined effect of these studies showed that smear layer removal signifi-

TABLE 2. Comparisons within 26 eligible articles, sorted by first author name, with level of significance, mean, and standard deviation for each side of the comparison

No.	Author	Ref. No.	Year	Sample Size		Test Site	Test Type	Obturation Type	Sealer Type	Sig.	SD		Mean	
				G1	G2						G1	G2	G1	G2
1	Economides et al.	12	2004	15	15	1	2	1	3	0	—	—	—	—
2	Economides et al.	12	2004	15	15	1	2	1	2	0	—	—	—	—
3	Cobankara et al.	21	2004	20	20	1	2	1	3	1	0.35	0.26	0.73	0.51
4	Cobankara et al.	21	2004	20	20	2	2	1	3	1	0.33	0.14	0.37	0.20
5	Cobankara et al.	21	2004	20	20	1	2	1	3	1	0.47	0.25	0.68	0.37
6	Cobankara et al.	21	2004	20	20	2	2	1	3	1	0.30	0.14	0.31	0.18
7	Park et al.	31	2004	10	10	2	1	2	3	0	—	—	—	—
8	Park et al.	31	2004	10	10	2	1	2	3	1	—	—	—	—
9	Clark-Holke et al.	22	2003	10	10	1	4	1	3	1	—	—	—	—
10	Timpawat et al.	20	2001	15	15	1	2	2	4	2	5.10	15.30	13.00	16.90
11	Goya et al.	33	2000	10	10	1	1	1	1	0	—	—	—	—
12	Goya et al.	33	2000	10	10	1	1	1	1	1	—	—	—	—
13	Von Fraunhofer et al.	34	2000	12	12	1	3	2	3	1	3.43	4.25	7.32	5.26
14	Von Fraunhofer et al.	34	2000	12	12	1	3	1	3	1	1.28	3.66	8.56	6.65
15	Von Fraunhofer et al.	34	2000	12	12	1	3	1	3	1	2.66	0.88	8.36	9.14
16	Froes et al.	23	2000	11	12	1	1	2	1	0	1.40	0.90	5.20	3.70
17	Froes et al.	23	2000	12	12	1	1	1	1	1	1.00	1.30	4.30	3.60
18	Froes et al.	23	2000	12	12	1	1	2	1	2	1.10	1.20	4.30	6.50
19	Froes et al.	23	2000	12	12	1	1	1	1	2	1.30	1.20	3.60	5.50
20	Economides et al.	19	1999	20	20	1	3	1	1	0	0.38	0.33	0.70	0.65
21	Economides et al.	19	1999	20	20	1	3	1	3	1	0.28	0.21	0.40	0.29
22	Timpawat and Sripanaratanakul	29	1998	10	10	1	1	2	0	0	1.50	1.38	3.27	2.91
23	Timpawat and Sripanaratanakul	29	1998	10	10	1	1	2	4	0	0.78	0.54	1.32	0.67
24	Timpawat and Sripanaratanakul	29	1998	10	10	1	1	2	1	0	0.82	0.68	1.16	0.82
25	Taylor et al.	18	1997	10	10	2	1	1	3	1	—	—	6.30	3.85
26	Taylor et al.	18	1997	10	10	2	1	2	3	0	—	—	5.30	3.40
27	Taylor et al.	18	1997	10	10	2	1	1	1	0	—	—	6.30	6.15
28	Taylor et al.	18	1997	10	10	2	1	2	1	0	—	—	5.55	5.10
29	Taylor et al.	18	1997	10	10	2	1	2	3	0	—	—	3.80	3.70
30	Taylor et al.	18	1997	10	10	2	1	2	3	0	—	—	4.30	3.75
31	Taylor et al.	18	1997	10	10	2	1	2	3	0	—	—	9.25	9.15
32	Taylor et al.	18	1997	10	10	2	1	2	3	0	—	—	4.95	4.15
33	Taylor et al.	18	1997	10	10	2	1	2	3	0	—	—	8.70	8.55
34	Taylor et al.	18	1997	10	10	2	1	1	4	0	—	—	5.40	4.65
35	Vassiliadis et al.	16	1996	21	21	2	1	1	1	1	1.49	1.11	4.46	2.61
36	Vassiliadis et al.	16	1996	21	21	2	5	1	1	1	0.91	0.32	1.24	0.60
37	Chailertvanitkul et al.	24	1996	20	20	2	4	1	2	0	—	—	—	—
38	Chailertvanitkul et al.	24	1996	20	20	2	4	2	2	0	—	—	—	—
39	Behrend et al.	25	1996	20	20	2	4	2	1	1	—	—	—	—
40	Behrend et al.	25	1996	5	5	2	4	2	0	0	—	—	—	—
41	Goldberg et al.	26	1995	10	10	1	1	1	4	0	0.41	0.50	0.24	0.48
42	Lloyd et al.	30	1995	22	22	1	1	1	2	0	—	—	—	—
43	Lloyd et al.	30	1995	22	22	1	1	2	2	0	—	—	—	—
44	Karagoz-Kucukay and Bayirli	17	1994	14	19	1	3	2	2	1	—	—	—	—
45	Karagoz-Kucukay and Bayirli	17	1994	14	18	1	3	2	0	1	—	—	—	—
46	Tidswell et al.	27	1994	20	20	2	1	1	4	0	0.38	0.73	1.68	2.04
47	Tidswell et al.	27	1994	20	20	2	1	1	4	0	1.58	1.70	2.29	2.37
48	Saunders and Saunders	28	1994	18	18	2	1	2	4	1	1.16	0.52	1.78	1.02
49	Saunders and Saunders	28	1994	18	18	2	1	1	4	0	1.29	0.62	2.03	1.56
50	Saunders and Saunders	28	1994	18	18	2	1	2	4	0	1.12	0.89	1.21	1.61
51	Saunders and Saunders	28	1994	18	18	2	1	1	4	0	1.32	0.43	2.54	1.01
52	Gencoglu et al.	15	1993	20	20	1	1	1	1	1	5.20	3.70	7.50	7.50
53	Gencoglu et al.	15	1993	20	20	1	1	2	1	1	3.30	1.10	4.50	0.90
54	Gencoglu et al.	15	1993	20	20	1	1	2	1	1	2.10	2.50	4.10	2.40
55	Saunders and Saunders	14	1992	15	15	2	1	1	1	1	1.53	0.29	4.26	1.13
56	Saunders and Saunders	14	1992	15	15	2	1	1	4	1	1.65	1.23	6.83	3.72
57	Cergneux et al.	9	1987	15	14	1	1	1	1	1	0.97	0.98	2.13	1.11
58	Cergneux et al.	9	1987	15	14	1	1	1	1	1	0.97	0.76	2.13	0.86
59	Evans and Simon	13	1986	8	8	1	1	1	1	0	0.00	0.00	0.00	0.00
60	Evans and Simon	13	1986	8	8	1	1	1	0	0	3.60	3.60	3.40	3.40
61	Evans and Simon	13	1986	8	8	1	1	2	1	0	2.00	2.00	1.10	1.10
62	Evans and Simon	13	1986	8	8	1	1	2	0	0	3.80	3.80	4.10	4.10
63	Kennedy et al.	32	1986	15	15	1	1	3	1	1	2.95	4.13	9.47	9.47

TABLE 2. (Continued)

No.	Author	Ref. No.	Year	Sample Size		Test Site	Test Type	Obturation Type	Sealer Type	Sig.	SD		Mean	
				G1	G2						G1	G2	G1	G2
64	Goldberg et al.	36	1985	11	11	1	4	1	3	0	—	—	—	—
65	Madison and Krell	35	1984	10	10	1	1	1	1	0	1.50	3.70	4.30	5.15

G1, group 1: group with smear layer.

G2, group 2: group without smear layer.

Test site: 1, apical; 2, coronal.

Test type: 1, dye leakage; 2, fluid filtration; 3, electrochemical; 4, bacterial leakage; 5, volumetric dye leakage.

Obturation type: 1, cold technique; 2, warm technique; 3, gutta-percha softened with chloroform.

Sealer type: 0, without sealer; 1, zinc oxide–eugenol–based sealer; 2, $Ca(OH)_2$-based sealer; 3, resin-based sealer; 4, glass-ionomer-based sealer; 5, silicone-based sealer.

Sig., significance: 0, no significant difference; 1, significant difference in favor of removing the smear layer; 2, significant difference in favor of keeping the smear layer.

cantly improves the apical and coronal seal, and this effect is not dependent on obturation type, site of leakage test, sealer type, type of dye used, duration of the test, or year of publication.

The low number of selected comparisons and the great variation in the techniques prevented the combination of the results of studies that used other evaluation techniques, although in all of these groups, the number of comparisons suggesting removal of the smear layer outnumbered those in favor of keeping it.

The following explanations have been drawn by several authors to support the idea of removing the smear layer:

1. It has an unpredictable diameter and volume, because a great portion of it consists of water (9).
2. It contains bacteria and necrotic tissue (1, 146, 148, 149).
3. It may act as a substrate for the bacteria, letting them penetrate deeper into the dentinal tubules (150).
4. It may limit the optimum penetration of disinfecting agents, medicaments, and root canal filling materials into dentinal tubules (1, 146, 148, 149).

On the other hand, some authors believe in keeping the smear layer during canal preparation, because it can block the dentinal tubules, preventing the inward and outward movement of bacteria and other irritants (2–4, 151, 152). However, Williams and Goldman (144) reported that the smear layer is not a complete barrier and can only delay bacterial penetration.

It was found in this study that the mean value of methylene blue penetration was significantly greater than that of India ink. This could be

TABLE 3. Number of insignificant and significant comparisons within selected articles, listed by criteria

Criteria/group	Insignificant Comparisons [n (%)]	Significant Comparisons [n (%)] Smear Layer Removed	Significant Comparisons [n (%)] Smear Layer Kept	Total [n (%)]	p
Sample size					
$n < 30$	23 (65.7)	10 (28.6)	2 (5.7)	35 (100)	0.046
$n \geq 30$	12 (40)	17 (56.6)	1 (3.3)	30 (100)	
Test site					
Apical	17 (45.9)	17 (45.9)	3 (8.1)	37 (100)	0.2
Coronal	18 (64.3)	10 (35.7)	0 (0)	28 (100)	
Test type					
Dye leakage	28 (63.6)	14 (31.8)	2 (4.5)	44 (100)	0.078
Fluid filtration	2 (28.6)	4 (57.1)	1 (14.3)	7 (100)	
Electrochemical	1 (14.3)	6 (85.7)	0 (0)	7 (100)	
Bacterial	4 (66.7)	2 (33.3)	0 (0)	6 (100)	
Volumetric leakage	0 (0)	1 (100)	0 (0)	1 (100)	
Obturation technique with gutta-percha					
Cold	17 (47.2)	18 (50)	1 (2.8)	36 (100)	0.22
Warm	18 (64.3)	8 (28.6)	2 (7.1)	28 (100)	
Chloroform softened	0 (0)	1 (100)	0 (0)	1 (100)	
Sealer type					
No sealer	4 (80)	1 (20)	0 (0)	5 (100)	0.23
Zinc oxide–eugenol	9 (39.1)	12 (52.2)	2 (8.7)	23 (100)	
$Ca(OH)_2$	5 (83.3)	1 (16.7)	0 (0)	6 (100)	
Resin	9 (45)	11 (55)	0 (0)	20 (100)	
Glass ionomer	8 (72.7)	2 (18.2)	1 (9.1)	11 (100)	
Year of publication					
<1995	11 (50)	11 (50)	0 (0)	22 (100)	0.42
≥1995	24 (55.8)	16 (37.2)	3 (7)	43 (100)	
Total	35 (53.84)	27 (41.5)	3 (4.61)	65 (100)	0.001

The p-value represents the comparison made between different groups for each criterion using Fischer's exact test. The last row represents the number of different types of reported comparisons being compared using χ^2 test.

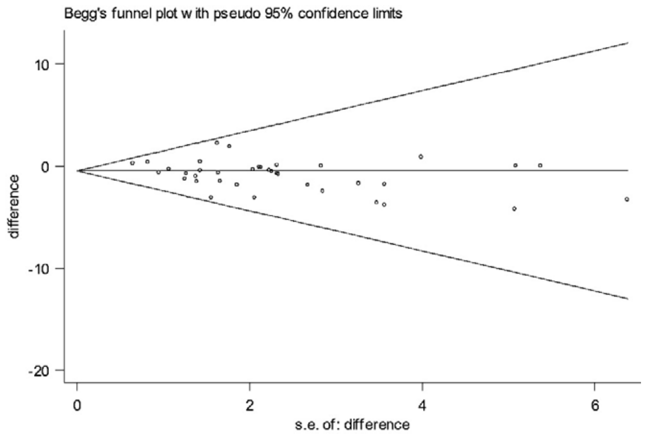

Figure 1. Funnel plot for the effect of smear layer removal in studies that used dye leakage method; this graph illustrates low risk of publication bias among recruited papers.

explained by the acidic portion of methylene blue, which may dissolve the inorganic tissue and allow further penetration (132), or by its smaller molecular size in comparison with India ink (16).

Although no evidence of publication bias was found in the data, it should be mentioned that the study was limited to papers published in the English language. In addition, because of the methodological variations, it was not possible to combine the results of all of the studies; as a matter of fact, only the results of studies that used the dye leakage test were combined in this study. Moreover, almost all of the articles reviewed in this study explored the issue with ex vivo tests, and it should be kept in mind that extending their results to clinical conditions should be performed with extensive caution. This should be considered in interpreting the results of the current study. Hence, it is suggested by the authors to perform clinical research studies using in vivo tests to address this controversy from another point of view.

In the current study, the authors were forced to exclude a few papers from final review because they did not report a valid mean and standard deviation; thus, investigators are encouraged to report their findings in a way compatible with the previously published research projects on the same subject if they want their findings to be compared or evaluated in combination with similar articles in future reviews.

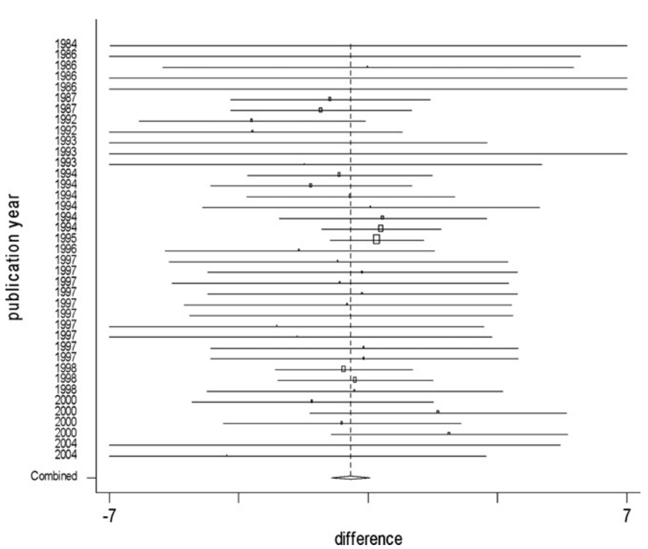

Figure 2. The Forest plot for the effect of smear layer removal on dye leakage results; the box and horizontal lines show the point estimation with 95% confidence interval of effects in each study, respectively. The diamond at the bottom of the figure shows the combine effect based on the random effect model.

TABLE 4. Effects of potential factors influencing the results of keeping or removing the smear layer for comparisons made with the dye leakage test, calculated with meta-regression

Potential Effective Factor	Coefficient	z	p
Smear layer removal	−0.37	−2.31	0.021
Obturation technique	0.56	0.19	0.84
Site of leakage study	−0.26	−0.81	0.42
Sealer type	0.016	−0.14	0.89
Dye type	0.012	0.03	0.97
Duration of leakage test	0.034	0.87	0.38
Year of publication	0.012	0.37	0.71
Sample size	−0.018	0.94	0.35

In conclusion, considering the conditions of these in vitro leakage studies, smear layer removal improves the fluid-tight seal of the root canal system, whereas other factors, such as the obturation technique or the sealer used, did not produce significant effects. The dye leakage test was the favorite means for evaluating the effects of smear layer removal, and the site of the test, type of dye, and year of publication did not significantly affect the final outcome (38–147).

Acknowledgments

The authors thank Dr Masoud Parirokh for his valuable comments on the final draft of the paper and Dr Niloofar Khalesseh and Mr. Hessam Shahriari for their help in preparing the manuscript. The authors also thank Kerman University of Medical Sciences, Kerman, Iran for their financial support.

References

1. McComb D, Smith DC. A preliminary scanning electron microscopic study of root canals after endodontic procedures. J Endod 1975;1:238–42.
2. Michelich VJ, Schuster GS, Pashley DH. Bacterial penetration of human dentin in vitro. J Dent Res 1980;59:1398–403.
3. Pashley DH, Michelich V, Kehl T. Dentin permeability: effects of smear layer removal. J Prosthet Dent 1981;46:531–7.
4. Safavi KE, Spangberg LS, Langeland K. Root canal dentinal tubule disinfection. J Endod 1990;16:207–10.
5. Yang SE, Bae KS. Scanning electron microscopy study of the adhesion of *Prevotella nigrescens* to the dentin of prepared root canals. J Endod 2002;28:433–7.
6. Czonstkowsky M, Wilson EG, Holstein FA. The smear layer in endodontics. Dent Clin North Am 1990;34:13–25.
7. Foster KH, Kulild JC, Weller RN. Effect of smear layer removal on the diffusion of calcium hydroxide through radicular dentin. J Endod 1993;19:136–40.
8. Lester KS, Boyde A. Scanning electron microscopy of instrumented, irrigated and filled root canals. Br Dent J 1977;143:359–67.
9. Cergneux M, Ciucchi B, Dietschi JM, Holz J. The influence of the smear layer on the sealing ability of canal obturation. Int Endod J 1987;20:228–32.
10. White RR, Goldman M, Lin PS. The influence of the smeared layer upon dentinal tubule penetration by plastic filling materials. J Endod 1984;10:558–62.
11. Cohen S, Hargreaves KM. Pathways of the pulp, vol. 10, 9th ed. Philadelphia: Elsevier International, 2006.
12. Economides N, Kokorikos I, Kolokouris I, Panagiotis B, Gogos C. Comparative study of apical sealing ability of a new resin-based root canal sealer. J Endod 2004;30:403–5.
13. Evans JT, Simon JH. Evaluation of the apical seal produced by injected thermoplasticized gutta-percha in the absence of smear layer and root canal sealer. J Endod 1986;12:100–7.
14. Saunders WP, Saunders EM. The effect of smear layer upon the coronal leakage of gutta-percha fillings and a glass ionomer sealer. Int Endod J 1992;25:245–9.
15. Gencoglu N, Samani S, Gunday M. Evaluation of sealing properties of Thermafil and Ultrafil techniques in the absence or presence of smear layer. J Endod 1993;19:599–603.

16. Vassiliadis L, Liolios E, Kouvas V, Economides N. Effect of smear layer on coronal microleakage. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1996;82:315–20.
17. Karagoz-Kucukay I, Bayirli G. An apical leakage study in the presence and absence of the smear layer. Int Endod J 1994;27:87–93.
18. Taylor JK, Jeansonne BG, Lemon RR. Coronal leakage: effects of smear layer, obturation technique, and sealer. J Endod 1997;23:508–12.
19. Economides N, Liolios E, Kolokuris I, Beltes P. Long-term evaluation of the influence of smear layer removal on the sealing ability of different sealers. J Endod 1999;25:123–5.
20. Timpawat S, Vongsavan N, Messer HH. Effect of removal of the smear layer on apical microleakage. J Endod 2001;27:351–3.
21. Cobankara FK, Adanr N, Belli S. Evaluation of the influence of smear layer on the apical and coronal sealing ability of two sealers. J Endod 2004;30:406–9.
22. Clark-Holke D, Drake D, Walton R, Rivera E, Guthmiller JM. Bacterial penetration through canals of endodontically treated teeth in the presence or absence of the smear layer. J Dent 2003;31:275–81.
23. Froes JA, Horta HG, da Silveira AB. Smear layer influence on the apical seal of four different obturation techniques. J Endod 2000;26:351–4.
24. Chailertvanitkul P, Saunders WP, MacKenzie D. The effect of smear layer on microbial coronal leakage of gutta-percha root fillings. Int Endod J 1996;29:242–8.
25. Behrend GD, Cutler CW, Gutmann JL. An in-vitro study of smear layer removal and microbial leakage along root-canal fillings. Int Endod J 1996;29:99–107.
26. Goldberg F, Artaza LP, De Silvio A. Apical sealing ability of a new glass ionomer root canal sealer. J Endod 1995;21:498–500.
27. Tidswell HE, Saunders EM, Saunders WP. Assessment of coronal leakage in teeth root filled with gutta-percha and a glass of ionomer root canal sealer. Int Endod J 1994;27:208–12.
28. Saunders WP, Saunders EM. Influence of smear layer on the coronal leakage of Thermafil and laterally condensed gutta-percha root fillings with a glass ionomer sealer. J Endod 1994;20:155–8.
29. Timpawat S, Sripanaratanakul S. Apical sealing ability of glass ionomer sealer with and without smear layer. J Endod 1998;24:343–5.
30. Lloyd A, Thompson J, Gutmann JL, Dummer PM. Sealability of the Trifecta technique in the presence or absence of a smear layer. Int Endod J 1995;28:35–40.
31. Park DS, Torabinejad M, Shabahang S. The effect of MTAD on the coronal leakage of obturated root canals. J Endod 2004;30:890–2.
32. Kennedy WA, Walker WA 3rd, Gough RW. Smear layer removal effects on apical leakage. J Endod 1986;12:21–7.
33. Goya C, Yamazaki R, Tomita Y, Kimura Y, Matsumoto K. Effects of pulsed Nd:YAG laser irradiation on smear layer at the apical stop and apical leakage after obturation. Int Endod J 2000;33:266–71.
34. Von Fraunhofer JA, Fagundes DK, McDonald NJ, Dumsha TC. The effect of root canal preparation on microleakage within endodontically treated teeth: an in vitro study. Int Endod J 2000;33:355–60.
35. Madison S, Krell KV. Comparison of ethylenediamine tetraacetic acid and sodium hypochlorite on the apical seal of endodontically treated teeth. J Endod 1984;10:499–503.
36. Goldberg F, Bernat MI, Spielberg C, Massone EJ, Piovano SA. Analysis of the effect of ethylenediaminetetraacetic acid on the apical seal of root canal fillings. J Endod 1985;11:544–7.
37. Arisu HD, Bala O, Alimzhanova G, Turkoz E. Assessment of morphological changes and permeability of apical dentin surfaces induced by Nd:Yag laser irradiation through retrograde cavity surfaces. J Contemp Dent Pract 2004;5:102–13.
38. Behr M, Rosentritt M, Regnet T, Lang R, Handel G. Marginal adaptation in dentin of a self-adhesive universal resin cement compared with well-tried systems. Dent Mater 2004;20:191–7.
39. Carrotte P. Endodontics: part 8. Filling the root canal system. Br Dent J 2004;197:667–72.
40. Karadag LS, Bala O, Turkoz E, Mihcioglu T. The effects of water and acetone-based dentin adhesives on apical microleakage. J Contemp Dent Pract 2004;5:93–101.
41. Ozturk B, Ozer F, Belli S. An in vitro comparison of adhesive systems to seal pulp chamber walls. Int Endod J 2004;37:297–306.
42. Prati C, Nucci C, Toledano M, Garcia-Godoy F, Breschi L, Chersoni S. Microleakage and marginal hybrid layer formation of compomer restorations. Oper Dent 2004;29:35–41.
43. Sevimay S, Oztan MD, Dalat D. Effects of calcium hydroxide paste medication on coronal leakage. J Oral Rehabil 2004;31:240–4.
44. Davis JL, Jeansonne BG, Davenport WD, Gardiner D. The effect of irrigation with doxycycline or citric acid on leakage and osseous wound healing. J Endod 2003;29:31–5.
45. Ferrari M, Tay FR. Technique sensitivity in bonding to vital, acid-etched dentin. Oper Dent 2003;28:3–8.
46. Hossain M, Yamada Y, Nakamura Y, Murakami Y, Tamaki Y, Matsumoto K. A study on surface roughness and microleakage test in cavities prepared by Er:YAG laser irradiation and etched bur cavities. Lasers Med Sci 2003;18:25–31.
47. Al-Turki M, Akpata ES. Penetrability of dentinal tubules in adhesive-lined cavity walls. Oper Dent 2002;27:124–31.
48. De La Macorra JC, Escribano NI. Comparison of two methods to measure permeability of dentin. J Biomed Mater Res 2002;63:531–4.
49. Moodley D, Grobler SR. Dentine bonding agents: a review of adhesion to dentine. SADJ 2002;57:234–8.
50. Murray PE, Smyth TW, About I, Remusat R, Franquin JC, Smith AJ. The effect of etching on bacterial microleakage of an adhesive composite restoration. J Dent 2002;30:29–36.
51. Shigetani Y, Tate Y, Okamoto A, Iwaku M, Abu-Bakr N. A study of cavity preparation by Er:YAG laser: effects on the marginal leakage of composite resin restoration. Dent Mater J 2002;21:238–49.
52. Tay FR, King NM, Chan KM, Pashley DH. How can nanoleakage occur in self-etching adhesive systems that demineralize and infiltrate simultaneously? J Adhes Dent 2002;4:255–69.
53. Tay FR, Pashley DH, Suh BI, Carvalho RM, Itthagarun A. Single-step adhesives are permeable membranes. J Dent 2002;30:371–82.
54. Tay FR, Pashley DH, Yoshiyama M. Two modes of nanoleakage expression in single-step adhesives. J Dent Res 2002;81:472–6.
55. Torabinejad M, Handysides R, Khademi AA, Bakland LK. Clinical implications of the smear layer in endodontics: a review. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2002;94:658–66.
56. Wimonchit S, Timpawat S, Vongsavan N. A comparison of techniques for assessment of coronal dye leakage. J Endod 2002;28:1–4.
57. Cox CF, Tarim B, Kopel H, Gurel G, Hafez A. Technique sensitivity: biological factors contributing to clinical success with various restorative materials. Adv Dent Res 2001;15:85–90.
58. Gilbert SD, Witherspoon DE, Berry CW. Coronal leakage following three obturation techniques. Int Endod J 2001;34:293–9.
59. Gilhooly RM, Hayes SJ, Bryant ST, Dummer PM. Comparison of cold lateral condensation and a warm multiphase gutta-percha technique for obturating curved root canals. Int Endod J 2000;33:415–20.
60. Kubo S, Yokota H, Sata Y, Hayashi Y. Microleakage of self-etching primers after thermal and flexural load cycling. Am J Dent 2001;14:163–9.
61. Ozok AR, De Gee AJ, Wu MK, Wesselink PR. The influence of resin composite and bonded amalgam restorations on dentine permeability in Class II cavities in vitro. Dent Mater 2001;17:477–84.
62. Al-Dewani N, Hayes SJ, Dummer PM. Comparison of laterally condensed and low-temperature thermoplasticized gutta-percha root fillings. J Endod 2000;26:733–8.
63. Al-Dewani N, Hayes SJ, Dummer PM. Evaluation of the Trifecta obturating technique. Endod Dent Traumatol 2000;16:75–83.
64. Ferrari M, Mason PN, Vichi A, Davidson CL. Role of hybridization on marginal leakage and bond strength. Am J Dent 2000;13:329–6.
65. Al-Jazairy YH, Louka AN. Effect of bonded amalgam restorations on microleakage. Oper Dent 1999;24:203–9.
66. Davalou S, Gutmann JL, Nunn MH. Assessment of apical and coronal root canal seals using contemporary endodontic obturation and restorative materials and techniques. Int Endod J 1999;32:388–96.
67. Kimura Y, Yamazaki R, Goya C, Tomita Y, Yokoyama K, Matsumoto K. A comparative study on the effects of three types of laser irradiation at the apical stop and apical leakage after obturation. J Clin Laser Med Surg 1999;17:261–6.
68. Kytridou V, Gutmann JL, Nunn MH. Adaptation and sealability of two contemporary obturation techniques in the absence of the dentinal smear layer. Int Endod J 1999;32:464–74.
69. Mannocci F, Innocenti M, Bertelli E, Ferrari M. Dye leakage and SEM study of roots obturated with Thermafill and dentin bonding agent. Endod Dent Traumatol 1999;15:60–4.
70. Yamazaki R, Goya C, Tomita Y, Kimura Y, Matsumoto K. Study on apical leakage of the teeth after argon laser treatment and obturation. J Clin Laser Med Surg 1999;17:121–5.
71. Barkhordar RA, Russel T. Effect of doxycycline on the apical seal of retrograde filling materials. J Calif Dent Assoc 1998;26:842–5.
72. Caliskan MK, Turkun M, Turkun LS. Effect of calcium hydroxide as an intracanal dressing on apical leakage. Int Endod J 1998;31:173–7.
73. Santini A. Biocompatibility of dentine-bonding agents. 2. Pulpal considerations. Prim Dent Care 1998;5:69–72.
74. Sen BH, Buyukyilmaz T. The effect of 4% titanium tetrafluoride solution on root canal walls: a preliminary investigation. J Endod 1998;24:239–43.
75. Wu MK, de Gee AJ, Wesselink PR. Effect of tubule orientation in the cavity wall on the seal of dental filling materials: an in vitro study. Int Endod J 1998;31:326–32.
76. Youngson CC, Jones JC, Manogue M, Smith IS. In vitro dentinal penetration by tracers used in microleakage studies. Int Endod J 1998;31:90–9.
77. Pashley DH, Carvalho RM. Dentine permeability and dentine adhesion. J Dent 1997;25:355–72.

78. Saunders WP, Saunders EM. The root filling and restoration continuum: prevention of long-term endodontic failures. Alpha Omegan 1997;90:40–6.
79. Brannstrom M. Reducing the risk of sensitivity and pulpal complications after the placement of crowns and fixed partial dentures. Quintessence Int 1996;27:673–8.
80. Leonard JE, Gutmann JL, Guo IY. Apical and coronal seal of roots obturated with a dentine bonding agent and resin. Int Endod J 1996;29:76–83.
81. Meiers JC, Kresin JC. Cavity disinfectants and dentin bonding. Oper Dent 1996;21:153–9.
82. Perez F, Calas P, Rochd T. Effect of dentin treatment on in vitro root tubule bacterial invasion. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1996;82:446–51.
83. Sen BH, Piskin B, Baran N. The effect of tubular penetration of root canal sealers on dye microleakage. Int Endod J 1996;29:23–8.
84. Zoellner A, Herzberg S, Gaengler P. Histobacteriology and pulp reactions to long-term dental restorations. J Marmara Univ Dent Fac 1996;2:483–90.
85. Yap A, Stokes AN, Pearson GJ. An in vitro microleakage study of a new multi-purpose dental adhesive system. J Oral Rehabil 1996;23:302–8.
86. Hasegawa T, Retief DH, Russell CM, Denys FR. Shear bond strength and quantitative microleakage of a multipurpose dental adhesive system resin bonded to dentin. J Prosthet Dent 1995;73:432–8.
87. Sen BH, Wesselink PR, Turkun M. The smear layer: a phenomenon in root canal therapy. Int Endod J 1995;28:141–8.
88. Sultan M, Pitt Ford TR. Ultrasonic preparation and obturation of root-end cavities. Int Endod J 1995;28:231–8.
89. Trowbridge HO. Tooth sensitivity associated with the use of luting cements. Penn Dent J (Phila) 1995;94:5, 24–6.
90. Chigira H, Yukitani W, Hasegawa T, et al. Self-etching dentin primers containing phenyl-P. J Dent Res 1994;73:1088–95.
91. De Gee AJ, Wu MK, Wesselink PR. Sealing properties of Ketac-Endo glass ionomer cement and AH26 root canal sealers. Int Endod J 1994;27:239–44.
92. Gaintantzopoulou MD, Willis GP, Kafrawy AH. Pulp reactions to light-cured glass ionomer cements. Am J Dent 1994;7:39–42.
93. Prati C. What is the clinical relevance of in vitro dentine permeability tests? J Dent 1994;22:83–8.
94. Sim TP, Sidhu SK. The effect of dentinal conditioning on light-activated glass-ionomer cement. Quintessence Int 1994;25:505–8.
95. Soh G, Sidhu SK. The effect of smear layer removal on marginal contraction gaps. J Oral Rehabil 1994;21:411–7.
96. Suzuki S, Cox CF, White KC. Pulpal response after complete crown preparation, dentinal sealing, and provisional restoration. Quintessence Int 1994;25:477–85.
97. Tay FR, Gwinnett AJ, Pang KM, Wei SH. Structural evidence of a sealed tissue interface with a total-etch wet-bonding technique in vivo. J Dent Res 1994;73:629–36.
98. Yap UJ, Stokes AN, Pearson GJ. Concepts of adhesion: a review. N Z Dent J 1994;90:91–7.
99. Cox CF. Etiology and treatment of root hypersensitivity. Am J Dent 1994;7:266–70.
100. Barkmeier WW, Douville CJ, Matranga LF. Shear bond strength, microleakage and scanning electron microscopy study of the Clearfil Liner Bond System. Asian J Aesthet Dent 1993;1:85–90.
101. Duke ES. Adhesion and its application with restorative materials. Dent Clin North Am 1993;37:329–40.
102. Ferrari M, Cagidiaco MC, Gesi A, Balleri P. Preliminary report of an experimental design for in vivo testing of bonded restorations applied to a new enamel-dentinal bonding agent. J Prosthet Dent 1993;70:465–7.
103. Mixson JM, Richards ND, Mitchell RJ. Effects of dentin age and bonding on microgap formation. Am J Dent 1993;6:72–6.
104. Yu XY, Joynt RB, Davis EL, Wieczkowski G Jr. Adhesion to dentin. J Calif Dent Assoc 1993;21:23–9.
105. Bakland LK. Pulp biology research: is the frog still deaf? J Dent Res 1992;71:1752–3.
106. Barkmeier WW, Cooley RL. Laboratory evaluation of adhesive systems. Oper Dent 1992;Suppl 5:50–61.
107. Brannstrom M, Coli P, Blixt M. Effect of tooth storage and cavity cleansing on cervical gap formation in Class II glass-ionomer/composite restorations. Dent Mater 1992;8:327–31.
108. Cox CF. Effects of adhesive resins and various dental cements on the pulp. Oper Dent 1992;5:165–76.
109. Jordan RE, Suzuki M. The ideal bonding system. J Can Dent Assoc 1992;58:623–5.
110. Pashley DH. The effects of acid etching on the pulpodentin complex. Oper Dent 1992;17:229–42.
111. Prati C, Simpson M, Mitchem J, Tao L, Pashley DH. Relationship between bond strength and microleakage measured in the same Class I restorations. Dent Mater 1992;8:37–41.
112. Retief DH, Mandras RS, Russell CM, Denys FR. Phosphoric acid as a dentin etchant. Am J Dent 1992;5:24–8.
113. Scherer W, Binder D, David S, Mercurio C, Mello T. Effects of pH on the dentin surface. J Esthet Dent 1992;4:159–63.
114. Lumley PJ, Walmsley AD, Walton RE, Rippin JW. Effect of precurving endosonic files on the amount of debris and smear layer remaining in curved root canals. J Endod 1992;18:616–9.
115. Stabholz A, Khayat A, Weeks DA, Neev J, Torabinejad M. Scanning electron microscopic study of the apical dentine surfaces lased with ND:YAG laser following apicectomy and retrofill. Int Endod J 1992;25:288–91.
116. Swift EJ Jr, LeValley BD. Microleakage of etched-dentin composite resin restorations. Quintessence Int 1992;23:505–8.
117. Watson TF, Billington RW, Williams JA. The interfacial region of the tooth/glass ionomer restoration: a confocal optical microscope study. Am J Dent 1991; 4:303–10.
118. Wieczkowski G Jr, Yu XY, Davis EL, Joynt RB. Microleakage in various dentin bonding agent/composite resin systems. Oper Dent 1992;5:62–7.
119. Woody TL, Davis RD. The effect of eugenol-containing and eugenol-free temporary cements on microleakage in resin bonded restorations. Oper Dent 1992;17: 175–80.
120. Yu XY, Davis EL, Joynt RB, Wieczkowski G Jr. Origination and progression of microleakage in a restoration with a smear layer-mediated dentinal bonding agent. Quintessence Int 1992;23:551–5.
121. Abbott PV, Heijkoop PS, Cardaci SC, Hume WR, Heithersay GS. An SEM study of the effects of different irrigation sequences and ultrasonics. Int Endod J 1991;24: 308–16.
122. Gettleman BH, Messer HH, El Deeb ME. Adhesion of sealer cements to dentin with and without the smear layer. J Endod 1991;17:15–20.
123. Pashley DH. Dentin bonding: overview of the substrate with respect to adhesive material. J Esthet Dent 1991;3:46–50.
124. Pashley DH, Pashley EL. Dentin permeability and restorative dentistry: a status report for the American Journal of Dentistry. Am J Dent 1991;4:5–9.
125. Richardson D, Tao L, Pashley DH. Dentin permeability: effects of crown preparation. Int J Prosthodont 1991;4:219–25.
126. Watson TF, Billington RW, Williams JA. The interfacial region of the tooth/glass ionomer restoration: a confocal optical microscope study. Am J Dent 1991;4: 303–10.
127. White JM, Goodis H. In vitro evaluation of an hydroxyapatite root canal system filling material. J Endod 1991;17:561–6.
128. Yu XY, Joynt RB, Wieczkowski G, Davis EL. Scanning electron microscopic and energy dispersive x-ray evaluation of two smear layer-mediated dentinal bonding agents. Quintessence Int 1991;22:305–10.
129. Zidan O, Ross G, Lee IK, Gomez-Marin O, Yeh SH. The effect of dentin pre-treatment and heat-augmented cure on marginal gap formation of a dentin bonding agent. Dent Mater 1991;7:174–8.
130. Barkmeier WW, Huang CT, Hammesfahr PD, Jefferies SR. Bond strength, microleakage, and scanning electron microscopy examination of the Prisma Universal Bond 2 adhesive system. J Esthet Dent 1990;2:134–9.
131. Czonstkowsky M, Wilson EG, Holstein FA. The smear layer in endodontics. Dent Clin North Am 1990;34:13–25.
132. Greene HA, Wong M, Ingram TA 3rd. Comparison of the sealing ability of four obturation techniques. J Endod 1990;16:423–8.
133. Pashley DH. Clinical considerations of microleakage. J Endod 1990;16:70–7.
134. Tjan AH, Dunn JR. Microleakage at gingival dentin margins of Class V composite restorations lined with light-cured glass ionomer cement. J Am Dent Assoc 1990;121:706–10.
135. Wendt SL Jr, Jebeles CA, Leinfelder KF. The effect of two smear layer cleansers on shear bond strength to dentin. Dent Mater 1990;6:1–4.
136. Barkmeier WW, Huang CT, Hammesfabr PD, Jefferies SR. In vitro evaluation of two new dentin adhesive systems. J Esthet Dent 1989;1:164–7.
137. Barkmeier WW, Cooley RL. Shear bond strength, microleakage and SEM study of the XR Bond adhesive system. Am J Dent 1989;2:111–5.
138. Douglas WH. Clinical status of dentine bonding agents. J Dent 1989;17: 209–15.
139. Srisawaski S, Boyer DB, Reinhardt JW. The effect of removal of the smear layer on microleakage of Class V restorations in vitro. Dent Mater 1988;4:384–9.
140. Cergneux M, Ciucchi B, Dietschi JM, Holz J. The influence of the smear layer on the sealing ability of canal obturation. Int Endod J 1987;20:228–32.
141. Jodaikin A, Austin JC, Cleaton-Jones PE. Pulpal responses to amalgam restorations in cavities with and without smear layer removal. J Oral Pathol 1986;15:415–8.
142. Pashley DH, Depew DD. Effects of the smear layer, Copalite, and oxalate on microleakage. Oper Dent 1986;11:95–102.
143. Pashley DH. Dentin-predentin complex and its permeability: physiologic overview. J Dent Res 1985;64:613–20.
144. Williams S, Goldman M. Penetrability of the smeared layer by a strain of *Proteus vulgaris*. J Endod 1985;11:385–8.

145. Brannstrom M. Smear layer: pathological and treatment considerations. Oper Dent Suppl 1984;3:35–42.
146. Yamada RS, Armas A, Goldman M, Lin PS. A scanning electron microscopic comparison of a high volume final flush with several irrigating solutions: part 3. J Endod 1983;9:137–42.
147. Jodaikin A, Austin JC. The effects of cavity smear layer removal on experimental marginal leakage around amalgam restorations. J Dent Res 1981;60: 1861–6.
148. Wayman BE, Kopp WM, Pinero GJ, Lazzari EP. Citric and lactic acids as root canal irrigants in vitro. J Endod 1979;5:258–65.
149. Goldberg F, Abramovich A. Analysis of the effect of EDTAC on the dentinal walls of the root canal. J Endod 1977;3:101–5.
150. George S, Kishen A, Song KP. The role of environmental changes on monospecies biofilm formation on root canal wall by *Enterococcus faecalis*. J Endod 2005;31:867–72.
151. Galvan DA, Ciarlone AE, Pashley DH, Kulild JC, Primack PD, Simpson MD. Effect of smear layer removal on the diffusion permeability of human roots. J Endod 1994;20:83–6.
152. Drake DR, Wiemann AH, Rivera EM, Walton RE. Bacterial retention in canal walls in vitro: effect of smear layer. J Endod 1994;20:78–82.