

Effect of thickness on the sealing ability of some root canal sealers

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A fluid transport model study was used to evaluate the sealing ability of five root canal sealers, AH 26, Sealapex, Ketac Endo, Roth, and Kerr EWT, and a dental bonding agent at thicknesses of 0.05 mm (thin layer) and 0.3 mm (thick layer) with 270 standard human root sections obturated with sealer combined with standard gutta-percha cylinders. AH26 and Sealapex sealed more tightly in thick layers, whereas Ketac Endo, Johnson and Johnson Bonding Agent, Roth, and Kerr EWT sealed more tightly in thin layers. In thin layers J&J Bonding sealed more tightly than any other sealer tested. In thick layers AH 26 and Sealapex sealed more tightly than Ketac Endo and J&J Bonding Agent, and these sealed more tightly than Roth and Kerr EWT. These findings indicate that the thickness of the sealer layer significantly influences the sealing of a root canal filling and that the influence of thickness varies depending on the type of sealer. (*ORAL SURG ORAL MED ORAL PATHOL ORAL RADIOLOG ENDOD* 1995;80:338-44)

Complete obturation of the root canal system is an important part of root canal treatment to prevent re-infection of the cleaned pulp cavity. In vitro studies have shown that the most widely used root canal filling, gutta-percha, seals significantly better when used in combination with sealer.^{1,2}

It is generally supposed that the amount of sealer should be minimized in favor of the gutta-percha,^{3,4} resulting in the development of various gutta-percha condensation techniques. This supposition is based on the reports that sealers are dissolved by time^{5,6} and that various types of sealers shrink during their setting, thus leaving unacceptable voids.^{7,8} In this aspect it was assumed that a thinner sealer layer results in a better seal,⁹ comparable to the use of luting cement to fix casting restorations. However, sealers may work in a different manner, because other physical properties such as flow or setting time may also influence the sealing ability.¹⁰

Although the previously mentioned axiom is widely accepted, little is known about the influence of the sealer thickness on its sealing ability. This thickness could be important, given that the thickness of the sealer layer varies depending on the filling technique used.¹¹ Recently, in a leakage study¹² with bovine root sections of 4 mm in a fluid transport model, it appeared that various sealers showed different sealing capacity at various thicknesses.

In our pilot study the thickness of the sealer AH26 (DeTrey, Konstanz, Germany) after cold lateral condensation and single-cone technique was measured at levels 1, 3, and 5 mm from the apical constriction. It was shown that the values varied, depending mainly on the level tested; as far as lateral condensation was concerned, the values ranged from 0 to 0.07 mm, 0 to 0.3 mm, and 0.02 to 0.4 mm, respectively. The sealer layer was thicker when single-cone technique was applied and ranged from 0.02 to 0.2 mm at 1 and 3 mm from the apex and from 0.1 to 0.5 mm at 5 mm from the apex.

The purpose of this study was to evaluate in human roots the sealing ability of five root canal sealers and a dental bonding agent at two different thicknesses by simulating the layers of sealer present after cold lateral condensation or single-cone gutta-percha techniques with the fluid transport model.

MATERIAL AND METHOD

The sealers tested in this study were AH 26 silver free, Sealapex (Kerr Mfg Co, Romulus, Mich.), Ketac

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Endo (Espe GmbH, Seefeld, Germany), Roth 811 (Roth International LTD, Chicago, Ill.), Kerr Pulp Canal Sealer Extended Working Time (EWT) (Kerr Mfg Co, Romulus, Mich.), and Johnson & Johnson Bonding Agent (Sao Jose dos Campos-SP, Brazil).

Two hundred seventy fully developed human maxillary central incisors stored in 10% neutral formalin were used. The crowns of the teeth were removed at the cemento-enamel junction with a sawing microtome with a diamond blade (Isomet 11-1180 Low Speed Saw, BU Ehler Ltd, Evanston, Ill.). The root tips were also removed in the same way, leaving roots 10 mm in length.

The outer surface of the roots were modified at their coronal end. A stone bur was used in a low-speed hand piece so that the smooth, round, final outline could fit better to the plastic tube of the fluid transport device. The root canals were then prepared with Gates Glidden drills (Maillefer, Ballaigues, Switzerland) up to size 6 (ISO size 150) under copious running water. In this way all prepared root canals were straight, round in cross section, and had the same diameter 1.5 mm. Organic and inorganic debris including the smear layer were removed by successive irrigation with 2% sodium hypochlorite, 17% ethylenediamine tetraacetic acid (pH 7.7), and again 2% sodium hypochlorite. For the specimens with which Ketac Endo would be tested, ethylenediamine tetraacetic acid was replaced by 40% citric acid,^{13, 14} because ethylenediamine tetraacetic acid was reported to reduce the adhesive strength of glass ionomer.¹⁵ The prepared roots were then stored in distilled water until obturation was performed.

One hundred fifty gutta-percha cylinders 10 mm high and 1.5 mm wide were made by injection of thermoplasticized gutta-percha (Ultrafil, Hygienic, Akron, Ohio) into the lumen of one part of a metal mold of respective dimensions, and after cooling was performed, the formed gutta-percha cylinder was pushed out. In the same way 120 gutta-percha cylinders 10 mm high and 1 mm wide were prepared.¹²

Forty root specimens were used for each sealer and were randomly divided in two equal groups; the root canals of the first group were coated with freshly mixed sealer and obturated with gutta-percha cylinders 1.5 mm in diameter. Because this cylinder just fitted the size of the canal, a slight pressure was applied to place the gutta-percha, thus leaving a very thin layer of sealer. The thickness of this layer was approximately 0.05 mm, varying from 0 to 0.07 mm as determined by a stereomicroscope (Zeiss, West Germany). In the second group both root canal walls and gutta-percha cylinders 1 mm in diameter were coated with sealer. The gutta-percha was then care-

fully inserted in the center of the canal. In this way a thick layer of sealer approximately 0.3 mm (range 0.17 to 0.47 mm) remained between the dentinal wall and the gutta-percha cylinder. After every two teeth were filled, a fresh mix of sealer was used.

Ten specimens filled with gutta-percha cylinders 1.5 mm in diameter without any sealer were used as positive control specimens. Another 20 specimens, which were used as negative control specimens, were filled with gutta-percha cylinders 1.5 mm in diameter and AH26.¹² All filled roots were kept at 37°C and 100% humidity for 1 week. Before testing was performed, the negative control specimens were totally coated with two layers of nail varnish. A small area of gutta-percha cylinder at both ends was then exposed by removal of the nail varnish together with a small amount of gutta-percha. A small-sized sharp dental excavator was used to check whether the gutta-percha itself leaked. Only the lateral surface of the 240 experimental roots and the 10 positive control specimens were coated with nail varnish.

Thereafter each obturated root specimen was mounted in a fluid transport device that was originally developed by Pashley et al.¹⁶ and thoroughly described by Wu et al.^{17, 18} With the original design of Pashley, a capillary tube was placed between coronal temporary fillings or retrograde root fillings and a pressurized reservoir. Fluid movement into the test specimens was then measured from the displacement of an air bubble in the capillary. Because a root canal filling is much longer than a temporary filling or a retrograde root filling, a longer duration of measurement was needed, because longer voids reduce the flux of fluid transport. Because the many connections under pressure in Pashley's setup may have the risk to leak during long-term measurements, the air bubble movement could be influenced, making the results less reliable. To avoid this problem the modified design had only the inlet connection to the root under pressure, whereas the other connections with the glass capillary containing the air bubble at the outlet side of the specimen were not under pressure (Fig. 1). In this way leakage at the inlet connection does not disturb the stability of the air bubble.

After mounting was performed, the capillaries were left, and no pressure was applied for 24 hours to allow the introduced air bubbles to obtain a stabilized initial position. The fluid transport was then measured by the displacement of the air bubble in the capillary tube by applying a headspace pressure of 60 kPa (0.6 atm) for 48 hours. The physical relations between the amount of fluid transport and the void dimensions (length, diameter) were also discussed in detail by Wu et al.¹⁷ The fluid transport results (F) were expressed

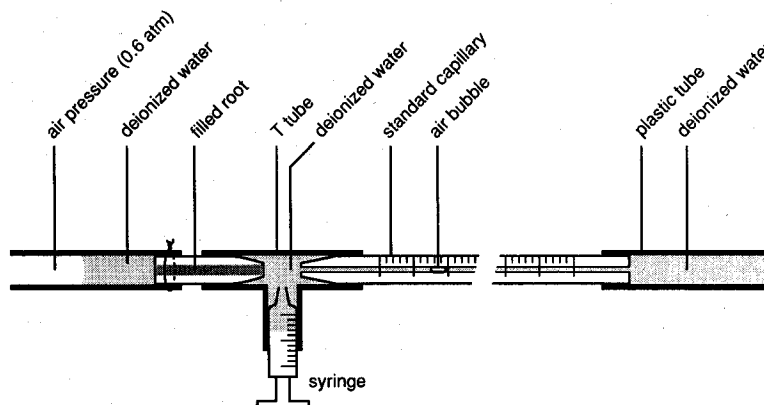


Fig. 1. Fluid transport device for leakage determination.

Table 1. Fluid transport results (F, in $\mu\text{L/day}$) of six sealers at 0.05 mm (thin layer) and 0.3 mm (thick layer)

Sealers		No. of root specimens			
		Score 1 $F = 0$	Score 2 $0 < F \leq 10$	Score 3 $F > 10$	Total
AH26	Thin	13	4	3	20
	Thick	18	2	0	20
Sealapex	Thin	12	4	4	20
	Thick	15	3	2	20
Ketac Endo	Thin	13	4	3	20
	Thick	6	8	6	20
Roth	Thin	9	6	5	20
	Thick	3	2	15	20
Kerr EWT	Thin	7	7	6	20
	Thick	2	3	15	20
J & J Bonding	Thin	18	2	0	20
	Thick	10	4	6	20

in $\mu\text{L/day}$ and scored 1 ($F = 0$), 2 ($0 < F \leq 10$), and 3 ($F > 10$).

Finally, statistical analysis of the data was performed to evaluate whether the variable thickness influenced the sealing ability of each sealer and whether any significant difference existed among the sealing abilities of the six sealers either in thin or in thick layers.

The association between layer and leakage for each sealer was described by Somers' D statistic. This is a specialized measure of association that takes into account the ordinal measurement scale of the variables and treats "Leakage" as the response variable, while "Layer" is regarded as the explanatory variable. The range of values of the statistics is $[-1, 1]$. The value 0 implies independence of the variables, whereas positive and negative values indicate that higher levels of the response correspond to higher and lower levels, respectively, of the explanatory variable.¹⁹

The differences among the sealing abilities of the sealers were evaluated with a log-linear regression model. Given that an observation is classified in row i of the variable "sealer," we denote the probability of classification in column j of leakage by π_{ij} . We use the ordinality of the response variable "leakage" by constructing logits for adjacent categories. A logit row effect model is

$$\log \left(\frac{\pi_j + 1/i}{\pi_j/i} \right) = \alpha_j + \mu_i, j = 1, 2, \\ i = 1, 2, \dots, 6 \text{ and } \beta_i = 0(1),$$

where α_j is the intercept parameter and the μ_i is the sealer effect of making response $j + 1$ instead of j .²⁰ There is a simple interpretation: for a pair of sealers i and n with $\mu_i > \mu_n$, the odds of classification in leakage score 2 instead of score 1 or in score 1 instead of score 3 are $e^{(\mu_i - \mu_n)}$ times higher for sealer i than for sealer n .

Table II. Somer's D Values and 95% confidence intervals estimated for the six sealers

Sealers	Somer's D	95% Confidence interval
AH26	-0.265	(-0.51, -0.02)
Sealapex	-0.160	(-3.06, 2.74)
Ketac Endo	0.350	(0.0404, 0.6596)
Roth	0.5	(0.2158, 0.7842)
Kerr EWT	0.468	(0.1838, 0.7522)
J&J Bonding	0.430	(0.18, 0.68)

RESULTS

The position of the air bubbles in the 20 negative control specimens remained stable during the 48 hours, whereas in the 10 positive control specimens the air bubbles moved too fast to be measured.

The results from the fluid transport measurements in the experimental groups are summarized in Table I. The values of Somer's D statistic for each sealer and the corresponding 95% approximate confidence intervals are shown in Table II. Interpretation of these values revealed that AH26 leaked significantly less in thick layers, whereas Ketac Endo, Roth Sealer, Kerr EWT, and J&J Bonding Agent leaked significantly more in thick layers. As far as Sealapex was concerned, there was just an indication that thick layers leaked less, because the value 0 was included in the confidence interval.

The statistical significance of the association between "sealer" and "leakage" was assessed by testing the hypothesis $H_0: \mu_1 = \mu_2 = \dots = \mu_6$. Under the model (1) this homogeneity of the row effects corresponds to independence. The test statistic is based on the difference of the likelihood ratios for the independence and the row effects model and has asymptotically a chi-squared distribution under H_0 with $df = 5$. The values of the statistic 17.06 for the thin layer and 59.24 for the thick layer show a very strong evidence of an association; the hypothesis of independence is rejected in both groups at level of significance smaller than 1%.

The estimated effects of type of material on leakage (μ_i) together with the asymptotic standard errors were calculated for both thick and thin layers and are shown in Table III. The further the μ_i falls in the positive direction, the greater the tendency is for more leakage. Further evaluation to assess whether these differences were statistically significant at the 95% level of significance revealed the following.

For the thick layer no significant difference was seen between (1) AH26 and Sealapex, (2) J&J Bonding Agent and Ketac Endo, and (3) Roth and Kerr EWT. Therefore it can be claimed that AH26 and Sealapex showed the best sealing ability at thick lay-

Table III. Estimated effect of sealer on leakage (μ_i) and asymptotic standard error (ASE)

Sealer	Thick layer		Thin layer	
	μ_i	ASE	μ	ASE
AH26	-1.87	0.57	0.01	0.29
Sealapex	-0.81	0.33	0.19	0.28
Ketac Endo	0.24	0.26	0.01	0.29
Roth	1.18	0.32	0.5	0.27
Kerr EWT	1.3	0.34	0.71	0.27
J&J Bonding	-0.029	0.26	-1.43	0.57

ers, followed by J&J Bonding Agent and Ketac Endo. Roth and Kerr EWT leaked more than any other sealer tested. For the thin layer only J&J Bonding Agent proved to seal significantly better than the other materials. There was only a tendency for AH26, Ketac Endo, and Sealapex to show better sealing ability than Roth and Kerr EWT.

DISCUSSION

This study sought to assess the influence of the thickness on the sealing ability of various sealers with the fluid transport model proposed by Wu et al.¹⁷ This method was proved to be not only much more sensitive than dye penetration for the detection of full-length voids along the root canal but also to be highly reproducible.^{17, 18} Moreover, a major advantage of the method is the ability to measure microleakage without destroying the root specimens. Therefore observation of the tendency of the tested materials to increase or decrease microleakage over time is also possible.

Because our interest was focused only on the influence of the thickness of the sealer layer, the experiment was so designed to exclude variables like anatomy, shape of prepared canal, and obturation technique. For this purpose attention was paid to achieve an exact diameter of the root canal and an exact diameter of gutta-percha cylinders. The considerable variation in the thickness of sealer layer can therefore be attributed to the inability to keep the gutta-percha cylinder at the center of the canal rather than by the very limited variation in the diameter of the prepared canal, the gutta-percha cylinder, or both. On the other hand, it seems enough to measure the sealing ability of sealer layer, whose thickness is within certain range and has clinical relevance, and not the preciseness. Because in this study the canal was drilled to a standard cylindric shape and filled with a standard cylinder, it seemed to us unnecessary to measure the layer at three different levels, as it was

Table IV. Summarized results from this study and the fluid transport study of Wu et al.¹² (in brackets)

Sealer		No. of specimens			
		Score 1 (BT*)	Score 2 (SL*)	Score 3 (GL*)	Total
AH26	Thin†	13 (1)	4 (3)	3 (16)	20 (20)
	Thick**	18 (7)	2 (5)	0 (8)	20 (20)
Sealapex	Thin†	12 (3)	4 (2)	4 (15)	20 (20)
	Thick‡	15 (6)	3 (6)	2 (8)	20 (20)
Ketac Endo	Thin†	13 (8)	4 (7)	3 (5)	20 (20)
	Thick‡	6 (4)	8 (7)	6 (9)	20 (20)
Roth§	Thin†	9 (3)	6 (8)	5 (9)	20 (20)
	Thick‡	3 (0)	2 (0)	15 (20)	20 (20)
Kerr EWT§	Thin	7 (3)	7 (8)	6 (9)	20 (20)
	Thick	2 (0)	3 (0)	15 (20)	20 (20)
J & J Bonding	Thin	18	2	0	20
	Thick	10	4	6	20

*BT (bacteria tight), SL (slight leakage) and GL (gross leakage) are the categories used in the study of Wu et al.¹², respectively corresponding to score 1, 2 and 3.

†Both studies: 0.05 mm

‡Present study: 0.3 mm

Wu et al.¹²: 0.25 mm

§Another ZnOE-based sealer (Tubliseal) was used in the study of Wu et al.¹²

done in the pilot work after the canals were prepared and filled by a conventional clinical manner.

Sealers used were selected because AH26 represents a well-known resin-based material and Sealapex a widely used calcium hydroxide-containing sealer. Roth sealer is one of the most widespread zinc oxide-eugenol cements, whereas Kerr EWT is a new sealer that allows 6 to 8 hours of working time after mixing. To our knowledge no leakage study has been performed for this sealer. Ketac Endo is a new glass ionomer cement that is also reported to be dentine-adhesive.²¹ This property of Ketac Endo was demonstrated by application of a relatively thick layer either without or with a single cone of gutta-percha. Research concerning the sealing ability of this specific type of glass ionomer product are so far limited.^{12, 22} Finally, we evaluated the J&J Dental Bonding Agent, which was the only self-curing agent commercially available to us. We were inspired by the results of Zidan and ElDeeb²³ and Zidan et al.,²⁴ who showed a dramatic improvement in the quality of sealing of root canals with various dentinal bonding agents.

Because the method of this study is so different from that of many previous studies, a comparison of our results with those seems to make little sense, with the exception of the one conducted by Wu et al.¹² Here comparison is possible because of the similarities in specimen preparation and leakage methods.

The results of Wu et al.¹² were expressed in "Bacteria tight," "slight leakage," or "gross leakage" categories, which were based on a calculation of the void size with Poiseuille's formula. Considering

the irregularity of the void shape, the biologic relevance of these calculated categories should be further evaluated. The results in this study have been expressed with scores. Because in the study of Wu et al.¹² the results of all the specimens that fell into "bacteria tight" category actually were 0, scores 1, 2, and 3 used in this study corresponded respectively to the three categories used in the study of Wu et al.¹²

Table IV summarizes the results of both studies. The same tendency was found for the various sealers to show different sealing capacity, depending on their thickness. It is also remarkable that both studies revealed the same types of sealers, namely AH26 and Sealapex, to seal better in thick layers. The number of specimens with score 1 corresponding to the "bacteria tight" category is considerably higher in this study. Various factors may have attributed to this difference. First of all, the effect of setting stresses may be less harmful on the sealing of a long root canal filling as on the 4 mm long fillings in Wu's study.¹² The debonding of the sealer from either the dentine or the gutta-percha may occur at many different locations throughout a 10 mm length, resulting in voids that are less likely to be connected with each other, whereas in 4 mm filled root sections the cracks can more easily propagate over the full length, thus showing leakage. Apart from that, in the study of Wu et al.¹² the diameter of the exposed surface of filling was 3 mm, whereas in this study only 1.5 mm. This difference may also contribute to the higher rate of leakage in their study. Also, the differ-

ent properties between human and bovine dentine may have played a role.²⁵⁻²⁸

Beyond the quantitative differences we have already discussed, the fact remains that the fluid transport model once again provided highly reproducible results and can therefore be strongly recommended for further leakage studies on endodontic materials.

With different methods Zidan and ElDeeb²³ found that canals obturated with laterally condensed gutta-percha and Scotchbond leaked significantly less than when gutta-percha and Tubliseal were used, whereas Zidan et al.²⁴ found that in terms of total elimination of leakage, the single-cone technique with Scotchbond performed better than the lateral condensation with the same agent and concluded that leakage is independent of the method of obturation when an adhesive sealer is used. In our study the sealing quality of the J & J Bonding Agent was poorer when the layer was thicker. This difference may reflect the difference in methods or the different mechanisms of bond formation between the dentine and the various types of bonding agents. In spite of the fact that the seal of the bonding agent tested in our experiment was not as promising as the previously mentioned one, we think that further investigations to provide more information on the endodontic use of bonding agents would be of value.

The zinc-oxide eugenol sealers showed the most leakage. This could be explained by their sudden set,¹² resulting in cracks in the materials.

The sealing quality of Ketac Endo at thick layers does not justify its use with single-cone gutta-percha techniques as advocated by its manufacturers. AH26 and Sealapex showed satisfactory sealing quality in thin layers, which was further improved in thick layers. Therefore, it seems that the principle, "the thinner the sealer the better the seal," should be partly reconsidered and applied mainly to those materials that showed definitely worse sealing qualities in thick layers such as zinc-oxide eugenol sealers and Ketac Endo.

The data obtained from this study should be evaluated with caution and kept in perspective relative to the clinical usage of the root canal sealers.

CONCLUSIONS

Under the conditions of this study the following conclusions can be drawn. (1) The thickness of the sealer layer significantly influences the sealing of a root canal filling. (2) The influence of thickness varies depending on the type of sealer. (3) AH 26 and Sealapex sealed more tightly in thick layers (0.3 mm), whereas Ketac Endo, J&J Bonding Agent, Roth, and Kerr EWT sealed more tightly in thin layers (0.05

mm). (4) In thin layers J&J Bonding Agent sealed more tightly than any other sealer tested. (5) In thick layers AH26 and Sealapex sealed more tightly than Ketac Endo and J&J Bonding Agent, and these sealed more tightly than Roth and Kerr EWT.

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