Microleakage of endodontically treated teeth with different dowel systems

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Statement of problem. Several new esthetic dowel systems are available for the restoration of endodontically treated teeth, but little is known about how effectively these dowels seal the restored teeth.

Purpose. The purpose of this in vitro study was to compare microleakage of 3 esthetic, adhesively luted dowel systems with a conventional dowel system.

Material and methods. The root canals of 41 human intact single-rooted extracted teeth were prepared using a step-back technique. The teeth were randomly divided into 4 experimental groups (n=10), and 1 tooth served as a positive control. The decoronated roots were obturated with gutta-percha using lateral condensation. Roots were restored with 1 of the following dowel systems according to the manufacturer's instructions: (1) stainless steel dowels (ParaPost), (2) glass fiber dowels (Snowpost), (3) resin-supported polyethylene fiber (Ribbond) dowels, or (4) zirconia dowels (Cosmopost). Using a fluid filtration method, coronal leakage of the specimens along the dowel space and root canal restorative material was measured. Fluid movement measurements were made at 2-minute intervals for 8 minutes to measure the presence of voids existing in the obturated canals, at 1 week, 3 months, and 6 months following dowel insertion. A repeated-measures analysis of variance (ANOVA) was used to analyze logarithmic transformations of data (time and dowel material) for significant differences. The Tukey HSD test and paired 2-tailed tests were used to perform multiple comparisons (α=.05).

Results. The data indicated that the leakage values varied according to the dowel system used (P<.01). There was significant interaction between dowel systems and time of testing (P<.01). The sealing ability of zirconia dowels decreased over time (P<.01), but sealing abilities of stainless steel and resin-supported polyethylene fiber dowels remained constant (P>.05). The sealing ability of glass fiber dowels increased at 3 months (P=.032) and remained constant over the next 3 months (P=.758). Statistically, resin-supported polyethylene fiber and glass fiber dowels showed the lowest coronal leakage when compared with stainless steel and zirconia dowels at all time periods (P<.01). There were no significant differences between resin-supported polyethylene fiber and glass fiber dowels at any time period. The initial leakage measurement in zirconia dowel and stainless steel dowels were similar (P=.914), but became significantly different at 3 and 6 months (P<.01).

Conclusion. Resin-supported polyethylene fiber dowels and glass fiber dowels tested exhibited less microleakage compared to zirconia dowel systems. The latter system should be further evaluated because of its unacceptable level of leakage. (J Prosthet Dent 2004;92:163-9.)

CLINICAL IMPLICATIONS

The resin-supported polyethylene fiber and glass fiber dowel systems tested may be promising alternatives to the stainless steel and zirconia dowel systems with respect to microleakage.

Endodontically treated teeth are known to present a higher risk of biomechanical failure than vital teeth.[1-3] Dowels are generally needed to allow clinicians to replace missing tooth structure and restore pulpless teeth. The choice of an appropriate restoration for endodontically treated teeth is guided by strength and esthetics. Until recently, available prefabricated dowels were made of metal, and their use resulted in complex combinations of materials (dentin, metal dowels, cements, and core materials) with widely different degrees of rigidity.[4,5] The restoration of endodontically treated teeth with metal-free materials having physical properties similar to those of dentin has become a major objective in dentistry. The tooth-colored dowels have improved the esthetics of teeth restored with dowels and cores.[6,7]

Christel et al[8] observed that zirconia dowels, introduced in the late 1980s, exhibited high flexural

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strength and fracture toughness. Kwiatkowski and Geller[9] reported that zirconia dowels could be silanated and bonded with a resin luting agent. As an alternative to composite cores bonded to zirconia dowels, a new indirect technique allows the addition of a heat-pressed ceramic core to a zirconia dowel to form an all-ceramic tooth-colored dowel and core.[10]

Glass fiber–supported resin dowel systems were introduced in 1992.[11] The dowels are composed of unidirectional glass fibers embedded in a resin matrix that strengthen the dowels without compromising the modulus of elasticity.[11] Another advantage of glass fibers is that they distribute stress over a broad surface area, increasing the load threshold at which the dowel begins to show evidence of microfractures.[12] Fiber-reinforced dowels are reported to reduce the risk of tooth fractures and display higher survival rates than teeth restored with zirconia dowels.[7]

Ribbond (Ribbond, Seattle, Wash) is a polyethylene woven fiber ribbon that the manufacturer has suggested for use with composite to fabricate dowels and cores.[13] With this woven ribbon and commonly available adhesive restorative materials, esthetic dowels and core foundations can be made more easily.

Higher endodontic failure rates have been reported to be the result of coronal leakage when endodontically treated teeth are not adequately restored.[14-16] A cemented dowel should be capable of providing a satisfactory coronal seal for the root canal space, depending on the sealing properties of the cement used.[17] The rationale for using adhesive luting agents is based on the premise that dowels bonded to dentin will reinforce the tooth and help retain the dowel and the restoration.[18]

Selecting the appropriate adhesive and luting procedure for bonding dowels to root dentin is a further challenge. Sealing is expected to be effective owing to recent improvements in the bonding ability of adhesive resin luting agents.[12] Moreover, various types of bonding systems can be used in combination with different resin luting agents.[19] In a recent investigation, carbon fiber dowel and core foundations cemented with dentin-bonding agents and resin luting agents showed less microleakage than those luted with glass ionomer and zinc phosphate cements.[20] Resin luting agents may be polymerized through a chemical reaction, a light-polymerization process, or a combination of both mechanisms.[19] Most current resin luting agents polymerize with a dual-polymerizing process that requires light exposure to initiate the reaction.[19] However, it has been reported that light-polymerized composites generate more polymerization shrinkage stress and exhibit less flow than autopolymerized composites.[21] The contraction stress produced could exceed 20 MPa.[22]

In the past, leakage of endodontic materials has been measured by penetration of dyes, isotopes, microorganisms, or by electrochemical means.[23] A fluid filtration method was developed by Derkson et al[24] to quantitatively measure microleakage around coronal restorations. This technique was modified and used by Wu et al[25] to measure the microleakage of root canal restorative materials and provides quantitative volumetric data.[26] The use of positive pressure helps eliminate problems caused by entrapped air or fluid,[27] and it is convenient for repeating measurements that can be made over short periods of time.[20] It is more meaningful to know the volume of fluid that flows through an obturated root canal system than the length of a dyed gap in the obturation.[20] The method is nondestructive, therefore, as it allows repeated measurements on the same specimens. The sensitivity of the system can be adjusted by altering the pressure used and altering the diameter of the measurement micropipette.[19,26,28]

There is little information available in the literature on the sealing ability of the new esthetic endodontic dowels cemented with resin luting agents. The purpose of this in vitro study was to compare sealing properties of 3 adhesively luted dowel systems: glass fiber dowels (GFD), resin-supported polyethylene fiber dowels (RSPFD), and zirconia dowels (ZD) with a stainless steel dowel (SSD) system. Measurements were made using a modified fluid transport test model[25,26] at time intervals of 1 week, 3 months, and 6 months. The hypothesis tested was that coronal leakage in roots restored with fiber-supported dowels is similar to leakage in roots restored with SSD or ZD.

MATERIAL AND METHODS

To evaluate whether the type of dowel system and testing time influenced coronal leakage, 4 different dowel systems (SSD, GFD, RSPFD, and ZD) and 3 time periods (1 week, 3 months, 6 months) were selected. Forty-one mandibular first premolar teeth with straight root canals, anatomically similar root segments, and fully developed apices, extracted for periodontal reasons, were selected. The teeth were cleaned of soft tissue and calculus, decoronated apical to the cementoenamel junction with a slow-speed diamond saw (Isomet; Buehler, Lake Bluff, Ill), and stored in deionized water until used. To standardize root canal lengths for the experiment, the roots were sectioned to uniform lengths of 17 mm. The pulp tissue was removed with a barbed broach (Dentsply-Maillefer, Ballaigues, Switzerland). Canal patency was determined by passing a file (size 10 K-file; Dentsply-Maillefer) through the apical foramen. Canal working lengths were established 1.0 mm short of the apical foramina. A step-back technique was used for canal instrumentation. The same operator instrumented all root canals to the same size (#55 file; Dentsply-Maillefer). During instrumentation, canals were irrigated with 1 mL of 5.25% NaOCl. Upon completion of the instrumentation, the roots were randomly divided into 4 groups of 10 each, and 1 root served as a positive control.

Before obturation, the root canals were dried with paper points (Dentsply-Maillefer), and standardized gutta-percha points (Dentsply-Maillefer) were selected as master points. The root canals were filled with a resin sealer (AH Plus; Denstply DeTrey, Konstanz, Germany), in conjunction with the laterally condensed gutta-percha technique. The sealer was introduced into canals using a lentulo spiral instrument (Dentsply-Maillefer). Master gutta-percha points were coated with the sealer and placed in the canals to the working length. A finger spreader (Dentsply-Maillefer) was then inserted into the canals to a level approximately 1 mm short of the working length. Nonstandardized fine gutta-percha points were used with lateral condensation until the canals were obturated. Coronal root canal openings were then filled with a provisional material (Cavit-G; 3M ESPE, St Paul, Minn) and the gutta-percha–filled roots were placed in a humidor (100% relative humidity) for 1 week at 37°C. Each dowel was marked at a point 10 mm from its apical end. A line was drawn around the dowel at this point, and all dowels were cut to a 10-mm length with a water-cooled diamond fissure bur. This procedure standardized the dowel lengths and established diameter similarity between dowels with tapered designs. Gutta-percha was removed from the coronal part of the root canal with Peeso reamers (Dentsply-Maillefer). The dowel spaces were all prepared to a depth of 10 mm with special preparation drills supplied with each system, and the dowels were cemented flush with coronal root surfaces.

For the SSD specimens, a dowel space was prepared in each root using a 1.50-mm-diameter drill supplied with the prefabricated dowel (ParaPost System, Lot MT 32102; Coltene/Whaladent, Cuyahoga Falls, Ohio). Zinc polycarboxylate cement (Poly-F Plus, Lot 9902000427; Dentsply DeTrey) was mixed according to the manufacturer's instructions and then introduced into each dowel space using a lentulo spiral instrument (Dentsply-Maillefer). Then the dowels were coated with cement and slowly seated by finger pressure. Finger pressure was maintained until the cement set.[29] Excess cement was removed, and each specimen was cleaned with a moist cotton roll.

Dowel spaces were created for GFDs using the special drills supplied (Snowpost, Lot H 040; Carbotech, Ganges, France). The GFDs were 1.6 mm in diameter. A self-etching primer (Clearfil Liner Bond; Kuraray, Osaka, Japan) was applied to the walls of the dowel spaces, allowed to etch for 30 seconds, and gently air dried. A dual-polymerized bonding agent (Clearfil Liner Bond, Bond A and B; Kuraray) was then applied to the same walls. A dual-polymerizing resin luting agent (Panavia F; Kuraray) was mixed for 20 seconds and then

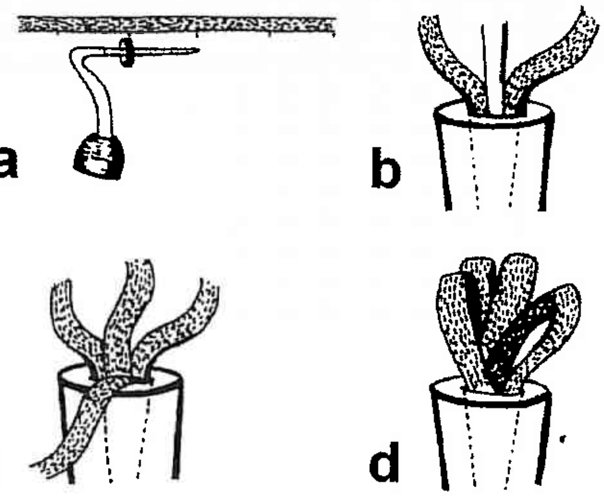

Fig. 1. Schematic view of preparation of resin-supported polyethylene fiber dowel. Modification of schematic from Eskitascioglu et al.[30]

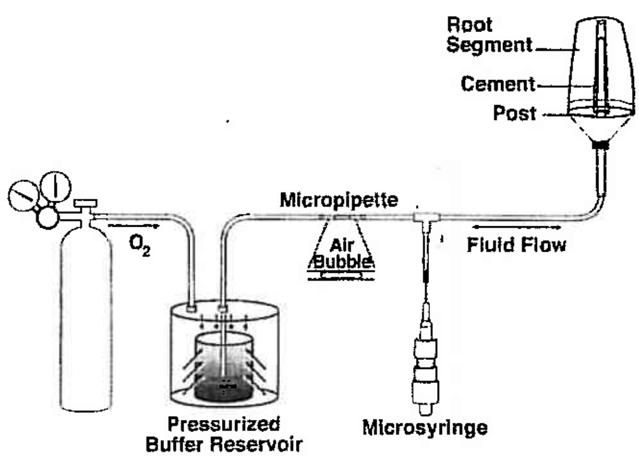

Fig. 2. Schematic view of apparatus used to measure fluid flow along root canals restored with different dowel systems. Movement of air bubble in micropipette per unit time provided means of measuring microleakage as fluid moved through system. Modification of schematic is from Bachicha et al.[20]

placed in the dowel spaces using a lentulo spiral instrument (Dentsply-Maillefer). Dowels were coated with cement and slowly seated by finger pressure. Excess cement was removed with an explorer. The light source was placed directly on the flat coronal tooth surfaces and cement was polymerized for 20 seconds, 350 mW/cm^2 (Hilux 350; First Medica, Greensboro, NC).

For the RSPFD specimens, dowels were made with polyethylene woven fiber ribbon as described by Eskitascioglu et al.[30] The canals were prepared with the same reamer used for the 1.6-mm GFD. Two pieces of 2-mm-wide and 24-mm-long ribbon (Ribbond) were chosen. The ribbon material was folded double, twisted,

Table I. Coronal leakage of 4 dowel systems used for restoring roots (L/min/cm H_2O)

Material	Time period	Fluid flow rate per H_2O
Stainless steel	1 week	$3.71 \times 10^{-4} \pm 1.0 \times 10^{-4}$
	3 months	$2.55 \times 10^{-4} \pm 1.69 \times 10^{-4}$
	6 months	$2.44 \times 10^{-4} \pm 1.57 \times 10^{-4}$
Glass fiber	1 week	$1.76 \times 10^{-4} \pm 0.90 \times 10^{-4}$
	3 months	$0.77 \times 10^{-4} \pm 0.65 \times 10^{-4}$
	6 months	$0.75 \times 10^{-4} \pm 0.50 \times 10^{-4}$
Resin-supported polyethylene fiber	1 week	$1.12 \times 10^{-4} \pm 0.67 \times 10^{-4}$
	3 months	$0.90 \times 10^{-4} \pm 0.76 \times 10^{-4}$
	6 months	$0.84 \times 10^{-4} \pm 0.48 \times 10^{-4}$
Zirconia	1 week	$5.09 \times 10^{-4} \pm 3.17 \times 10^{-4}$
	3 months	$13.27 \times 10^{-4} \pm 3.25 \times 10^{-4}$
	6 months	$14.82 \times 10^{-4} \pm 2.92 \times 10^{-4}$

Values are mean ± SD, n=10.
Positive control: 115 L/min/cm H_2O.

and soaked with unfilled resin (Clearfil Liner Bond; Kuraray). The self-etching primer (Clearfil Liner Bond) was applied to dowel space walls for 30 seconds and gently air dried. Adhesive (Clearfil Liner Bond) was applied to the walls and thinned with a brush. A dual-polymerizing composite luting agent (Variolink II Base Brown, 340/A4, Lot E13253; Ivoclar Vivadent, Schaan, Liechtenstein) was prepared with a catalyst (Variolink II Catalyst, low viscosity type, 210/A3, Lot E16059; Ivoclar Vivadent) and injected into the dowel spaces. All RSPFD specimens were prepared in the following manner. One piece of woven fiber saturated with a bonding agent was placed horizontally in a mesiodistal direction over the coronal dowel space opening and condensed into the dowel space with an endodontic plugger aligned over the center of the opening (Fig. 1). A second length of woven ribbon, prepared in the same manner, was placed over the first, in a buccolingual direction, and condensed into the dowel space. The free ends of the ribbons were folded over and condensed into the middle of the coronal opening. Condensation was continued until woven ribbons were pressed as tight as possible into the dowel space. Excess resin was removed, and the entire resin and woven fiber dowel were polymerized for 40 seconds with the same light-polymerizing unit.

ZDs (Cosmopost; Ivoclar Vivadent) 1.70 mm in diameter were used. Cosmoposts were seated in the dowel spaces and their lengths were adjusted. Then autopolymerizing acrylic resin (Meliodent; Bayer Dental, Newbury, UK) was used to fill spaces on either side of the dowel, buccal and lingual. The patterns created were removed, subsequently sprued, and invested (IPS Empress Investment; Ivoclar Vivadent) for the IPS Empress technique. After the burnout and preheating process, the core material (Empress-Cosmo, Lot D64021; Ivoclar Vivadent) was pressed onto the zirconium oxide post (Cosmopost; Ivoclar Vivadent) to fill spaces on either side of the dowel, buccally and lingually, by using the IPS Empress technique at 900°C and 5 bar.[31] The dowels were divested and all surfaces were carefully airborne-particle abraded. The bonding agent (Excite DC; Ivoclar Vivadent) was applied to dowel space walls with the applicator provided, and dual-polymerizing composite resin luting agent (Variolink II; Ivoclar Vivadent) was applied using the procedure described above in RSPFD specimens.

Measurement of the leakage

A modified fluid transport test method[26] was used to measure coronal leakage (Fig. 2). The sealing capabilities of the 4 dowel systems were quantified by following the movement of a tiny air bubble traveling within a constant bore 25-µL micropipette. All pipettes, syringes, and the plastic tubes used in the system were filled with distilled water. A micropipette was connected to the plastic tube and this plastic tube was connected to the tooth using an 18-gauge needle and a plastic cone as an adapter (Fig. 2). The plastic cones were sealed in place with a cyanoacrylate adhesive during fluid transport measurements. Water was drawn back approximately 2 mm with the microsyringe to introduce a tiny air bubble in the micropipette. The air bubble was adjusted to a suitable position within the micropipette with the syringe. Finally, compressed O_2 from a pressure tank at 121.5 KPa (1240 cm H_2O) was applied from the coronal ends of the specimens, forcing water through any voids along the dowel and root canal restoration material. The water movement displacing the air bubble in the capillary tube was measured per unit of time. Linear displacement of this air bubble was converted to volume displacement and recorded as the fluid transported. The values were expressed as L/min/cm H_2O.

For the specimen selected for the positive control, procedures for selection and instrumentation were the same as those described for the experimental groups, except the prepared root canal space was not obturated. The fluid flow rate through the 18-gauge needle and unfilled root canal was measured by weighing the amount of water that could pass through the needle in 1 minute (115 L/min/cm H_2O). This value served both as a positive control and as 100% leakage, to which the sealed values could be compared (as a percentage). Fluid measurements, indicating fluid passing through voids, were made at 2-minute intervals for 8 minutes and averaged.

The fluid transport results were analyzed with statistical software (SPSS PC, Version 10.0; SPSS, Chicago, Ill). A repeated-measures analysis of variance (ANOVA) test was used to analyze logarithmic transformations of data (time and dowel material) for significant differences. Log transformations were performed

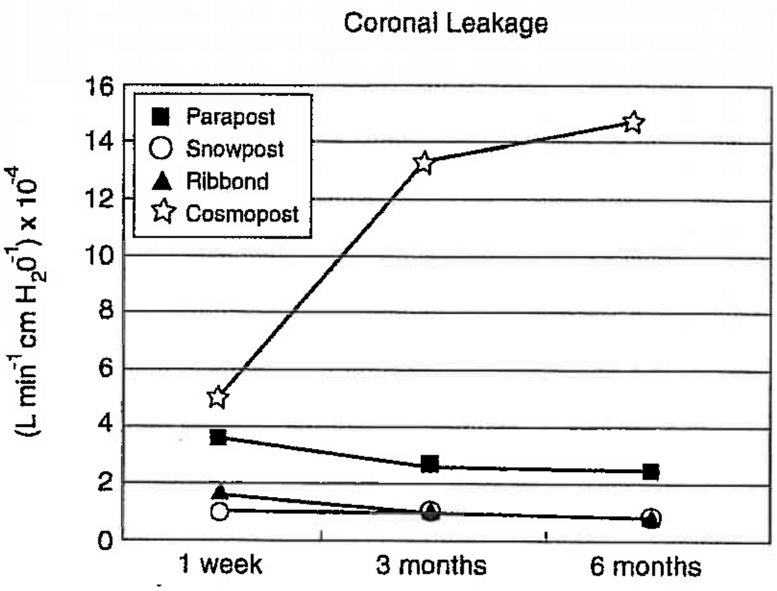

Fig. 3. Coronal leakage of different dowel systems at different time periods.

Table II. Results of repeated-measures ANOVA

	SS	*df*	MS	F	*P*
Dowel system	10.938	3	3.646	88.204	.000
Time of testing	7.143E–03	2	3.572E–03	.220	.803
Dowel system – time of testing	1.807	6	.301	18.590	.000

to account for differences in variance among groups. Tukey HSD and paired 2-tailed tests were used to perform multiple comparisons at a significance level set at α=.05.

RESULTS

The results of the sealing ability for the 4 dowel systems are shown in Figure 3 and Table I. The positive control specimen grossly leaked (115 L/min/cm H_2O). The repeated-measures ANOVA indicated that fluid microleakage values varied according to the dowel system used (SSD, GFD, RSPFD, and ZD) ($P<.001$). There were no significant differences among testing times (1 week, 3 months, 6 months). There was significant interaction between dowel system and time of testing ($P<.01$) (Table II). Sealing ability of ZD decreased over time ($P<.01$), but sealing abilities of SSD and RSPFD remained constant ($P>.05$). The coronal leakage of GFD increased over the first 3 months ($P=.032$) and remained constant over the last 3 months ($P=.758$). GFD and RSPFD showed the lowest coronal leakage when compared with SSD and ZD at all time periods ($P<.01$). There were no significant differences between GFD and RSPFD at any time period ($P>.05$) (Table III). Initial measurements in SSD and ZD were similar ($P=.914$), but were significantly different at 3 months and at 6 months ($P<.01$).

Table III. Results of Tukey HSD test

	SSD	GFD	ZD
1 week			
GFD	*		†
RSPFD	‡	NS	‡
ZD	NS	‡	
3 months			
GFD	‡		‡
RSPFD	†	NS	‡
ZD	‡		
6 months			
GFD	†		‡
RSPFD	†	NS	‡
ZD	‡		

*$P<.05$.
†$P<.01$.
‡$P<.001$.
SSD, Stainless steel dowel; *GFD,* glass fiber dowel; *RSPFD,* resin-supported polyethylene fiber dowel; *ZD,* zirconia dowel; *NS,* not significant.

DISCUSSION

The present study compared the leakage of roots restored with 4 different dowel systems. The results do not support the research hypothesis that no difference would be found in coronal leakage for the test specimens restored with different dowel systems. Specimens for testing were prepared using human teeth. The manufacturer's instructions were followed carefully when dowels were cemented to ensure that in vitro procedures were the same as those used clinically. In the current study, test specimens were not completely restored nor subjected to either thermal cycling or mechanical stress. These factors may limit the direct application of study results to in vivo situations.

Wu et al[25] advised controlling the length of the specimens, as well as canal diameters and canal anatomy, to reduce variations in microleakage studies. In the current study, root lengths (17 mm) and dowel space lengths (10 mm) were standardized to avoid anatomical variations and to obtain standardization. Three preformed dowel systems with close but different diameters were used in the current study, thus group diameter differences were a factor. Although the differences were small (1.5-1.7 mm), this limitation of the current study must also be considered.

Although statistical analysis showed significant differences in microleakage between groups of cemented dowels in this study, the measurements were highly varied within the groups. Certain clinical factors were a challenge to control, such as differences in root canal anatomy, volume of prepared dowel spaces, smear layer character, and patency of the dentinal tubules.[24]

The amount of fluid filtration measured in vitro has not been correlated with clinical conditions of failure. The hydrostatic pressure of 121.5 KPa (1240 cm H_2O) used in the present study was similar to that used by Wu et al[25] to measure microleakage of root canal restorative materials. This amount of hydrostatic pressure has the practical advantage of accelerating the detection of leakage where there are long interfaces created by dowels, cements, and dentin walls. In addition, the use of pressure provides comparable volumetric data, as opposed to gap measurements based on dye penetration techniques.[20]

In both the Fogel[26] study and the present study, fluid transport along SSDs cemented with zinc polycarboxylate cement was measured. A mean fluid transport value of $6.4 \times 10^{-3} \pm 6.3 \times 10^{-5}$ μL/min was recorded in Fogel's study.[26] In the current study a similar result ($3.7 \times 10^{-4} \pm 1.1 \times 10^{-4}$ L/min) was recorded. However, there were differences in experimental designs. Fogel used 100 KPa of hydrostatic pressure, 7-mm dowel space depths, and filtered from the apex (without gutta-percha obturation) to the crown. The current study applied filtration pressure in the opposite direction.

Prefabricated all-ceramic dowels offer excellent esthetic solutions for specific situations. The translucency of all-ceramic crowns is maintained with ceramic dowels and cores, since shade problems caused by opaque dowel and core materials are avoided.[10] According to the current study results, ZD combined with Excite DC and Variolink II showed the highest coronal leakage values. Other systems used in the present study (SSD, GFD, RSPFD) were prepared in a single-stage procedure, but the preparation of ZD specimens required 2 stages. Between the 2 stages, dowel space openings were closed with a provisional restorative material. It has been shown that bacteria remaining in the empty root canal spaces between appointments may continue growing,[15] and this may cause leakage.[25] This may explain the higher leakage found with the ZD system.

Two dowel systems (RSPFD and ZD) were luted with same resin luting agent, Variolink II. RSPFD showed the lowest leakage, whereas ZD showed the highest. The ZD system luting procedure, without silanization, may have been the basis of high leakage values and may indicate problems at the bond interface between ZD and Variolink II. However, further research is needed to clarify the nature of the bond between ZD and Variolink II resin cement.

A resin luting agent may create polymerization shrinkage stresses within the dowel space.[19] These shrinkage stresses were defined as the C factor, the ratio of bonded to unbonded surface areas.[21,22] It has been shown that C factors in dowel spaces may be as high as 200.[19] However, there are many factors that affect the adhesion processs.[22]

Resin luting agents have lower elastic moduli compared to the 2 materials they join.[30] Thus, a zone of highly concentrated loads and stresses is created. RSPFD and GFD systems have elastic moduli lower than ZD and SSDs, and their mechanical characteristics closely resemble dentin. RSPFD and glass fiber systems might have distributed stresses over a wider surface and limited microfractures inside the luting material. This may have resulted in less coronal leakage.

The reduced incidence of coronal leakage with the RSPFD and Variolink II combination was of particular interest in the present study. The technique may considerably reduce the clinical time needed for dowel fabrication. Moreover, the method does not require dowel space instrumentation to accommodate a prefabricated dowel, a point of particular concern when confronted with severely flared root canals and/or minimal remaining tooth structure.

CONCLUSION

Within the limitations of this study, the following conclusions were drawn.

1. RSPFD (Ribbond) and GFD (Snowpost) groups showed the lowest coronal leakage when compared with SSD (ParaPost) and ZD (Cosmopost) groups for all time periods ($P<.01$).

2. There were no significant differences in coronal leakage between RSPFD and GFD groups at any time period.

3. The coronal leakage of the ZD group decreased over time ($P<.01$), but coronal leakage of the SSD and RSPFD groups remained constant. The coronal leakage of the GFD group increased at 3 months ($P=.032$).

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