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The Sealing Properties of Two New Root Filling Materials: An In-Vitro Study.

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The Sealing Properties of Two New Root Filling Materials: An In-Vitro Study.

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The Sealing Properties of Two New Root Filling Materials: An In-Vitro Study.

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INTRODUCTION

It has been shown that the success of endodontic treatment is negatively influenced by the presence of bacteria remaining within the root canal system at the time of root filling (Zeldow & Ingle 1963, Engstrom et al. 1964, Sjögren et al. 1990). Studies have also shown the relationship between root canal infection and periradicular inflammation (Sundqvist 1976, Möller et al. 1981). Thus, the aim of endodontic therapy is based on the prevention or elimination of bacteria from the root canal system. This may be accomplished by root canal debridement through instrumentation, irrigation with various antimicrobial agents, and application of interappointment dressings prior to filling and sealing of the root canal.

It is generally accepted that the success rates of endodontic treatment are positively correlated with high technical quality of root fillings evaluated radiographically (Sjögren et al. 1990, Strindberg 1956, Kerekes & Tronstad 1979). One of the assumed qualities associated with high radiographic standards is a root filling which provides an effective seal against leakage. This root filling ideally prevents bacteria from the oral cavity as well as bacteria left in the canal following instrumentation and disinfection from maintaining and/or causing osteolysis.

Root Filling Materials

Various root filling materials have been used over the last 200 years to achieve this goal. Edward Hudson is generally given credit for having placed the first root filling in 1809 made of gold foil (Taylor 1922). Wood soaked in creosote was used to fill canals in the 1850's with a solution of Hill's stopping and chloroform or eucalyptus oil as the
cement (Curson 1965). Copper points were also used to fill root canals and they were later gold plated to prevent oxidation and subsequent discoloration (Anthony 1945).

Gutta percha was first introduced in 1867 for filling root canals (Bowman 1938). Before its use in endodontics, gutta percha was mixed with either zinc oxide or calcium oxide to form baseplates for dentures and also with chalk and wax for temporary fillings (Grossman 1976). The composition of gutta percha used in endodontics today contains 60-75 % zinc oxide, 19-22 % gutta percha, 1-17 % barium sulfates, and 1-4 % wax/resins, depending on the manufacturer (Friedman et al. 1975). Gutta percha and chloroform were combined by Bowman in 1895 and further developed and introduced as a chlorapercha technique for filling root canals by M.L. Rhein (Anthony 1945). A rosin-chloroform technique was introduced in 1911 whereby rosin in chloroform flooded the canal then gutta percha was dissolved with a pumping motion in this solution (Callahan 1914). Problems encountered with these chloroform techniques included overfilling and massive voids after evaporation of the chloroform. To deal with problems of voids in early root fillings the use of a cementing medium, or sealer, in conjunction with a solid gutta percha cone was introduced (Rickert 1925). At first only a single cone with sealer was used (Grove 1929), but later the technique was improved by using an instrument designed to facilitate lateral compaction of additional gutta percha cones (Grossman 1950).

Silver cones were introduced shortly after sealers and they were machined to the sizes of standard Kerr files (Jasper 1933). Advantages of these points included low brittleness, affordability, decreased incidence of overfilling, and ease of removal. Neobalsam was the sealing agent of choice and it was described as being non-irritating,
dimensionally stable, and slow-setting (Jasper 1933). Although silver points have almost been completely replaced by gutta percha, they are still available for use through many dental supply companies.

Various warm gutta percha techniques have also been introduced for filling root canals. The Schilder technique utilizes heat carriers to soften gutta percha and blunt end pluggers to vertically compress the softened gutta percha to create a dense three-dimensional obturation (Schilder 1967). The Microseal technique utilized frictional heat generated by a rotating compactor to soften and force gutta percha both laterally and apically (McSpadden 1980). The technique was later modified by the same author to overcome problems including breakage of compactors (Kerekes & Rowe 1982) and excessive heat generation (Saunders 1990). The Thermafil system utilizes a flexible plastic or stainless steel carrier, coated with a layer of alpha phase gutta percha. After heating in an oven the thermafil carrier is inserted into the root canal (Johnson 1978).

**Sealers**

Today, the majority of root fillings are composed of gutta percha and some type of sealer. Six classes of root canal sealers have been used in endodontics including different formulations of zinc oxide-eugenol (ZOE), calcium hydroxide, resin, glass ionomer, silicone, and chloroform (Orstavik 2005). ZOE materials have dominated the past 70 to 80 years. Early prototypes were Rickert’s sealer, available today in the form of Kerr Pulp Canal Sealer, and Grossman’s sealer, which has several commercial variants including Roth’s sealer and ProcoSol (Grossman 1976). Other ZOE sealers include Endomethasone and Tubliseal. Solvent-based sealers were also used throughout the early
to mid-twentieth century, with two of the most popular formulations being chloroform-resin and chloroform-gutta percha (Chloroperka N-Ø). These sealers have fallen out of favor due to radiographic voids and leakage along root fillings in-vitro caused by evaporation of the chloroform component (Beyer-Olsen et al. 1983).

Resin based sealers have also been used for many years with clinical success (Orstavik 1988), the two most popular being AH26 and AH Plus. Other resin sealers which have been used clinically include Diaket and EndoRez. Calcium hydroxide based sealers, including Sealapex, CRCS, and Apexit, were introduced in the 1980’s for stimulating hard tissue formation (Tronstad et al. 1988). Silicone-based sealers, including Endo-Fill and Roeko-Seal, were introduced because silicons have been used effectively as adhesives in kitchens, bathrooms, and construction work. More recently, a glass ionomer based sealer, Ketac-Endo, was introduced based on GI’s high affinity for bonding to dentin (Weiger et al. 1995).

**Microleakage**

The effect of microleakage on endodontic treatment outcome has been the subject of much investigation over the last 4 decades. An early prognosis study considered the leakage of tissue fluids apically through an inadequate root filling as a major cause for endodontic failure (Ingle 1985, Washington Study). In addition, many other studies have shown that more clinical failures are associated with inadequate root canal fillings than with root canal fillings of a high technical standard (Sjögren et al. 1990, Strindberg 1956, Kerekes & Tronstad 1979, Grossman et al. 1964, Molven & Halse 1988, Adenubi & Rule
1976, Petersson et al. 1986). Thus, based on clinical findings, researchers have continued to test root filling materials in-vitro for their ability to resist apical leakage.

The potential also exists for oral fluids and bacterial contamination of the root canal space due to dissolution of the coronal seal. When coronal restorations are lost or become defective the integrity of this coronal seal is compromised. Attempts have been made to correlate outcome of endodontic treatment to both the quality of the coronal restoration and the technical quality of the endodontic treatment through cross-sectional studies. One study found that the technical quality of the coronal restoration, determined radiographically, was more important than the technical quality of the endodontic treatment on treatment outcome (Ray & Trope 1995). Other studies have shown that both endodontic quality and restoration quality are equally important in treatment outcome (Kirkevang et al. 2000, Hommez et al. 2002), while yet another study found the coronal restoration only to be important if the endodontic treatment was satisfactory (Tronstad 2000).

Conversely, optimally prepared and filled root canals have been shown to resist bacterial penetration clinically upon challenge by direct oral exposure, caries and fracture. Teeth extracted for restorative reasons which had their root fillings exposed to the oral environment for 3 months to several years were evaluated histologically. Only 7 of 39 root tips displayed distinct inflammatory cell infiltrates, while only 2 of these specimens contained stainable bacteria. At the time of extraction, only 5 of 39 roots displayed osteolytic lesions radiographically (Ricucci & Bergenholtz 2003). Thus, the results of these studies are contradictory and the impact of coronal leakage on endodontic outcomes is still uncertain.
Since clinical studies are often difficult to conduct because of long observation periods and loss of subjects to follow-up, various in-vitro techniques have been introduced to evaluate the ability of different obturation techniques and filling materials to form an adequate coronal and apical seal. Most of these methods are based on the assessment of microleakage along the obturated root canal. In the 1990 volumes of Journal of Endodontics and International Endodontic Journal, leakage studies comprised almost 25% of scientific articles published (Wu et al. 1993a). Leakage of endodontic materials have been measured using radioactive isotopes, dye penetration techniques, microorganisms, electrochemical techniques, and with fluid filtration systems using positive pressure. The most popular method was linear penetration of dyes or radioisotopes along a root filling. This method was based on the assumption that linear penetration of the tracer would indicate the gap that existed between the root filling and root canal wall (Wu et al. 1993a).

**Radioisotope Studies**

Radioisotopes were first used to measure apical leakage in teeth filled with laterally condensed gutta percha and sealer. Common isotopes that were used included I$^{131}$, Rb$^{86}$, Na$^{22}$, S$^{35}$, Ca$^{45}$, P$^{32}$, glucose, and proline. After removal from the isotope solution the obturated teeth are sectioned either longitudinally or in cross-section through the root canal and placed on dental X-rays to produce autoradiographs (Matloff et al. 1982).

Dow and Ingle (1955) were the first to show with isotopes that well obturated root canals, determined radiographically, leaked less than poorly obturated root canals. These
findings supported the concept that a large number of root canal failures were caused by poor root canal fillings. Another study tested the apical and coronal leakage in teeth obturated with either gutta percha or silver cones and four different sealers (Marshall & Massler 1961). They found no real difference between Kerr, Wach’s paste, Klora-Perka N-Ø and Grossman’s sealers, but did show that when no sealer was used the canals showed gross leakage. This was one of the first studies that showed the importance of using a sealer in combination with a core filling material.

Kapsimalis & Evans (1966) used radioisotopes to show that laterally condensed gutta percha used with several different sealers leaked significantly less than single gutta percha cones or silver cones alone with sealer. Mixed results were found for the different sealers depending on what isotope was used. Other investigators tested the leakage in teeth filled with gutta percha, sealer, and gutta percha and sealer (Younis & Hembree 1976). They found that the gutta percha and sealer combination showed the least amount of apical leakage.

Quantitative methods have also been used to test leakage using Carbon-14 labeled human serum albumin. Two in-vitro studies found similar leakage patterns for vertical and lateral compaction of gutta percha/Grossman’s sealer, but significantly greater leakage values for Hydron, a material which is not currently used in clinical endodontics (Rhome et al. 1981, Director et al. 1982).

Thus, it can be generalized from the results of these isotope studies that using a sealer in conjunction with a core filling material is highly desirable, but that no differences in leakage are expected between vertical and lateral condensation techniques. Mixed results have been obtained for comparison of different sealers depending on what
isotope was used in the study. Although many isotope studies can be cited, the majority of leakage studies found in the literature are dye penetration studies. Dye penetration studies have been used to compare various sealers, obturation materials, and techniques.

**Dye Penetration Studies**

**Different sealers**

The sealing properties of many different sealers have been tested over the years. This technique involves removing the root sample from a dye and subsequent sample preparation via longitudinal sectioning, cross-sectioning, or a specialized clearing technique. Various dyes which have been used include methylene blue, India ink, eosin, silver stain, and Pelikan ink. The specimen is then viewed through a microscope and the leakage in millimeters or percentage of area involved is calculated.

An early dye study using methylene blue tested Diaket, Kerr sealer, and Grossman’s sealer in teeth obturated with both gutta percha and silver points. The author found no evidence of permeability thorough the core filling materials and Diaket, a polyketone compound, showed the lowest leakage (Stewart 1958). In another study, Grieve and Parkholm (1973) showed that Diaket sealer (0.6%) displayed significantly lower leakage scores than AH26 (3.29%), Endomethasone (3.12%), Tubliseal (2.58%), and Grossman’s sealer (44.1%).

Previous tracer studies have assessed the sealing ability of AH26, an epoxy-resin sealer, and have shown low leakage values compared to other sealers including Kerr Pulp Canal Sealer, Endomethasone, Kloroperka N-Ø, and AH Plus (Antoniazzi et al. 1968, Ford 1979, Zmener et al. 1997). AH26 has also shown the highest tensile bond strengths
to both dentin and gutta percha among other sealers tested including Procosol, CRCS, Diaket, Kloraperka N-Ø, Sealapex, Endomethasone, and Tubliseal (Orstavik et al. 1983, Wennberg 1990). Although AH26 has shown excellent sealing abilities, other studies have shown it to leak significantly more than Procosol and Endomethasone (Orstavik et al. 1983), Sealapex and Roth’s sealer (Madison et al. 1987), and Ketac Endo and Roth’s sealer (Barthel et al. 1999).

Zmener (1987) used methylene blue dye in teeth obturated with laterally compacted gutta percha after 48 hours setting time and showed that leakage increased with immersion time, but there was no significant difference between Sealapex, CRCS, and Tubliseal at 1, 3, and 10 days. Similarly, other authors found no statistically significant difference between Sealapex, Tubliseal, and Procosol sealers at any time period, but when no sealer was used in the controls the teeth displayed significant leakage (Hovland & Dumsha 1985). Although these two studies both showed similar leakage values for ZOE and calcium hydroxide sealers, it is difficult to compare the studies directly because of different dyes, setting times, and immersion times.

Other investigators tested the sealing efficacy of a new glass ionomer root canal sealer, Ketac Endo and Tubliseal to India ink after lateral compaction of gutta percha (Goldberg et al. 1995). They found no statistically significant difference between Ketac Endo with and without smear layer and Tubliseal. Ketac-Endo, Apexit, and Diaket sealers were compared in another study and they found Ketac-Endo to leak significantly more than the others after exposure to methylene blue dye for 7 days (Özata et al. 2005).

Even when different studies are compared which have tested the same sealer a high level of variation in leakage values can be seen. The shortest distance of dye
penetration in teeth obturated with gutta percha and Tubliseal was 0.14mm (Goldberg et al. 1995), while the largest was 9.25 mm (Thirawat & Edmunds 1989). Wide ranges in leakage are also seen with laterally compacted gutta percha and Roth’s 801 sealer. Depending on the study, dye penetration has ranged from 0.45 mm (Luccy et al. 1990) to 5.96 mm (Baumgartner & Krell 1990).

Therefore, drawing conclusions about what sealer provides the best seal may be quite difficult because of conflicting results of these and other in-vitro studies. It seems logical that the less leakage the better, although no evidence has yet been obtained that complete sealing is necessary.

Lateral condensation versus other techniques

Not only have different sealers been compared using lateral compaction of gutta percha as the model, but many studies have compared various other techniques to lateral compaction. Chloroform dipping of gutta percha with or without sealer present was shown to leak significantly more to various dyes than lateral compaction of gutta percha with Grossman’s sealer (Russin et al. 1980, Keane & Harrington 1984). Eucapercha and chloropercha techniques also showed more apical leakage than lateral compaction of gutta percha with mynol sealer (Zakariasen & Stadem 1982). These groups of studies showed the importance of evaporating chloroform from gutta percha cones before seating and also that using a sealer in conjunction with gutta percha is paramount.

Although lateral compaction of gutta percha remains the standard by which most clinicians fill roots, there are a variety of heat-softened gutta percha techniques available today. Several studies have found no difference in leakage to dyes between teeth
obturated with lateral compaction and various thermoplasticized gutta percha techniques as long as sealer was used (ElDeeb 1985, Mann & McWalter 1987, Greene et al. 1990). Conversely, others found teeth obturated with lateral compaction to leak significantly less than both high- and low-temperature injectable gutta percha techniques when using methylene blue linear dye measurements (LaCombe et al. 1988).

The McSpadden technique (1980), or thermomechanical compaction of gutta percha, was introduced as an alternative to the various heat softened techniques of obturation. Several studies have shown no significant differences between lateral compaction of gutta percha and thermomechanically obturated root canals to apical dye leakage using either the original or modified technique (Ishley & ElDeeb 1983, Saunders 1989, Gilhooly et al. 2001).

Another warm gutta percha technique which has gained popularity is the Thermafil device, which introduces softened gutta percha delivered on a metallic or plastic carrier (Johnson 1978). Several studies have shown no difference in the apical leakage between teeth obturated using lateral compaction and Thermafil regardless of the sealer used (Gutmann et al. 1993, Abarca et al. 2001, Schafer & Olthoff 2002). In another study, investigators used vacuum flask dye methods to test the apical leakage of 5 different obturation techniques. They found no statistical differences between single cone, lateral compaction, vertical condensation, Thermafil, and Ultrafil techniques (Dalat & Spångberg 1994). Lares and ElDeeb (1990) showed that teeth obturated with lateral condensation of gutta percha showed less leakage to India ink than teeth obturated with Thermafil. Conversely, teeth obturated with thermafil have also been shown to leak less than teeth obturated with lateral condensation of gutta percha (Beatty et al. 1989). Thus,
the literature seems contradictory and implies that the technique of obturation is not as important as the use of a sealer.

Consequently, it is difficult to draw firm conclusions on what materials or techniques display the lowest amount of leakage, despite the large number of publications available. Some investigators have stated that dyes and isotopes are merely indicators of ion exchange, diffusion, and capillary action rather than indicators of true leakage (Matloff et al. 1982, Wu et al. 1993b). In addition, these tracer studies do not provide information about the volume of tracer that penetrates through the root filling and can only be regarded as semi-quantitative, and thus yield a high level of variation (Wu & Wesselink 1993).

**Bacterial leakage studies**

Based on the assumption that leakage in the apical part of the obturated root canal could cause treatment failures (Ingle 1956, Ingle 1985, Adenubi & Rule 1976), many investigators performed leakage experiments by simply dipping the root tip into dye solution and measuring penetration from the apical to the coronal end. In contrast, leakage of tissue fluids containing bacteria and their products coronally through the canal into the periradicular tissues may contribute more to endodontic failures (Wu & Wesselink 1993, Ray & Trope 1995, Swanson & Madison 1987, Madison et al. 1987, Madison & Wilcox 1988). Also, because of the inherent problems associated with dye and radioisotope measurements of leakage including entrapped air (Oliver & Abbott 1991, Spångberg et al. 1989), delayed immersion times, immersion periods, tracers used,
and presence or absence of smear layer, bacterial leakage studies might be more meaningful and clinically relevant.

Bacterial penetration studies utilize a split chamber model where the filled root or root section is mounted between an upper chamber containing a test bacterium, and a lower chamber, which at the start contains sterile medium. After a period of time, bacterial growth may occur in the lower chamber, indicating that the test organism has passed along the entire root filling.

Torabinejad et al. (1990) looked at the coronal leakage of two different species of bacteria in root canal filled teeth and over 50% of the root canals were completely contaminated after a 19- and 42-day exposure to *S. epidermidis* and *P. vulgaris* respectively. Other investigators found only 7% of root-filled teeth to display complete leakage to *P. aeruginosa* after 50 days (Wu et al. 1993b). Trope et al. (1995) measured the amount of LPS which could move through obturated root canals with and without sealer. They found that 32% of teeth in the sealer group showed LPS in the lower chamber after 21 days.

Other studies have tested the sealing efficacy of certain sealers to microbial insult. Miletić et al. (2002) evaluated the penetration of *C. albicans* and a combination of bacteria through root canals filled with gutta percha and either AH26 or AH Plus. They found that leakage was present in almost half of all samples between 14 and 87 days, with no significant difference between the AH26 and AH Plus groups. Coronal leakage to *S. sanguis* was assessed in teeth obturated with laterally compacted gutta percha and three different sealers (Chailertvanitkul et al. 1996). The authors found no statistically significant difference in leakage between AH26, Apexit, and Tubliseal at 90 days. Three
different sealers were tested in a study using *E. faecalis* as the microbial marker and it was found that AH Plus (31%) displayed less leakage than Apexit (77%) and Ketac-Endo (53%) at 60 days (Timpawat et al. 2001).

Different methods of obturation have also been tested using microbial penetration. Three separate studies found no statistically significant differences in leakage between lateral and vertical condensation of gutta percha in teeth exposed to human saliva (Siqueira et al. 2000, Khayat et al. 1993, Carratú et al. 2002). Although there were no differences in leakage between different obturation techniques, there was significant bacterial penetration in all groups by 60 days ranging from 75-100%.

Thus, the research has shown that if left exposed to the oral environment every technique using a combination of gutta percha and sealer will leak and may become completely contaminated with bacteria between 14 and 90 days (Torabinejad et al. 1990, Chailertvanitkul et al. 1996, Khayat et al. 1993, Timpawat et al. 2001).

Potential limitations with this technique include its inability to provide volumetric data, similar results obtained for both small and large voids, and an inability to detect partial voids. In addition, the high variation in leakage results could be due in part to bacterial contamination.

**Electrochemical technique**

The first method developed for quantitatively measuring apical leakage along root fillings was an electrochemical technique by Jacobson and von Fraunhofer (1976). They measured the leakage in teeth obturated with vertical condensation of gutta percha and Rickert's sealer. Authors found that when root-filled teeth are placed in solutions of
potassium chloride (K\textsuperscript{+}Cl\textsuperscript{-}) an electric current is formed when ions pass through apical voids and reach an electrode placed in the coronal access causing the metal to corrode and thus completing the circuit. The time elapsed between immersion and current flow accurately denotes the K\textsuperscript{+}Cl\textsuperscript{-} penetration rate and the magnitude of the current will indicate the degree of penetration (Delivanis and Chapman 1982).

Other authors compared the electrochemical technique with the autoradiographic and dye penetration techniques in teeth obturated with lateral condensation of gutta percha and Procosol sealer (Delivanis & Chapman 1982). They found a poor correlation of the electric readings with the evaluations obtained with the dye and isotope techniques.

Although this technique seemed promising in providing quantitative measurements of apical leakage, it never became popular in endodontic research. This may be due to its technique sensitivity and poor correlation with dye and radioisotope results.

**Fluid filtration studies**

A new system which was originally developed by Derkson et al. (1986) to determine leakage around coronal restorations has been modified by Wu et al. (1993b) to test root canal filling leakage. In this model, fluid transport is measured by the movement of an air bubble in a fluid-filled capillary tube. This air bubble is controlled by a micro syringe and the volume of fluid passing through the root filling is computed in microliters. One of the advantages to using this method is its ability to measure microleakage without destroying the root specimens. Repeated observation of the same specimens over time to reveal changes in sealing ability is, therefore, possible. In
addition, this technique uses positive pressure to help rule out problems caused by entrapped air or fluid which has skewed results in previous tracer studies (Oliver & Abbott 1991, Spangberg et al. 1989, Wu et al. 1994a).

Fluid filtration was shown to be a more sensitive method for detecting endodontic leakage than both bacterial and dye penetration. Wu and colleagues (1993b) showed that although the majority of teeth did not show leakage to bacteria after 50 days, these same teeth showed more leakage when exposed to positive pressure fluids. In another study, authors showed that when teeth were subjected to fluid transport, dye penetrated significantly deeper, suggesting that entrapped air prevented dye penetration (Wu et al. 1994a). Camps & Pashley (2003) also found a poor correlation between dye and fluid filtration techniques. They found no difference in leakage between Pulp Canal Sealer, Sealapex, AH Plus, and Ketac-Endo using dye penetration, but found Sealapex to leak significantly more than the others when using fluid filtration tests.

In a series of studies, authors showed that all sealers including AH26, Ketac-Endo, Sealapex, and Tubliseal produced the best seal when the sealer was the thinnest (Wu et al. 1994b). After storing in water for 1 year, AH26, Ketac-Endo, and Tubliseal showed a reduction in leakage and gave significantly less leakage than Sealapex (Wu et al. 1995). Another study found Sealapex to leak significantly more than other sealers including AH26, Pulp Canal Sealer, and Ketac-Endo (Pommel et al. 2003).

Several studies have shown that AH26 has better sealing properties than ZOE-based, silicone-based, and glass ionomer sealers (Wu et al. 2004, Adanir et al. 2006, De Gee et al. 1994) and similar sealing properties to other resin-based sealers (Adanir et al. 2006). Conversely, other authors found no significant differences in leakage when
comparing AH26, AH Plus, Diaket, Apexit, and Ketac-Endo (Miletić et al. 1999) and between AH26 and Roekoseal (Cobankara et al. 2004).

Thus, as seen with various tracer techniques, fluid filtration studies can also lead to conflicting results even when comparing the same materials. Although it is still not clear what impact apical and coronal leakage has on the prognosis of root canal therapy, fluid filtration is generally considered the gold standard when assessing root canal leakage.

Many different materials have been proposed as root canal fillings, but none have replaced gutta percha, which is universally accepted as the gold standard for filling root canals. Although widely used, many feel that gutta percha is the weak link in endodontic therapy (Khayat et al. 1993, Trope et al. 1995). Fluid filtration as well as other techniques has shown that all root fillings composed of gutta percha and sealer will leak to some extent. Prior attempts were made with bonding agents and resins to decrease leakage inside the root canal, but many problems were encountered including poor working properties, radiopacity, and retreatability of the materials (Leonard et al. 1996, Ahlberg & Tay 1998, Imai & Komabayashi 2003). Therefore, if a new material could decrease leakage in the root canal and display similar handling properties as gutta percha, the success rates of endodontic treatment might be improved.

**New Root-Filling Materials**

Recently, a new root filling material has been introduced to the market. Resilon (Pentron Clinical Technologies, Wallingford, CT) is a thermoplastic synthetic polyester polymer which contains methacrylate resins, bioactive glasses, radiopaque
fillers and coloring agents. It performs like gutta percha, has the same handling properties, and may be softened by heat or chloroform for retreatment purposes. Master and accessory cones come in all ISO sizes and Resilon pellets are available as well for obturation using lateral condensation or warm thermoplasticized techniques. The Resilon system uses a self-etching Epiphany primer and dual curable Epiphany resin sealer (Pentron Clinical Technologies, Wallingford, CT).

Manufacturers attribute the excellent sealing ability of Resilon to the “monoblock” that is created by the adhesion of the Resilon cone to the Epiphany sealer, which adheres and penetrates into the dentin walls of the root canal system (Teixeira et al. 2004). This proposed bonding mechanism is achieved through chemical bonding between methacrylate moieties of both the Resilon cone and the Epiphany sealer; and also by a chemical/mechanical bond between sealer and dentin through formation of a hybrid layer, which consists of etched dentin, primer, and adhesive sealer (J Esthet Dent 1991).

Researchers have shown using a microbial leakage model that Resilon leaks significantly less than gutta percha and AH26 sealer regardless of the obturation technique used (Shipper et al. 2004). It has also been shown in dogs that when root filled teeth are intentionally inoculated with microorganisms, the Resilon filled teeth developed less periapical inflammation than those filled with gutta percha and AH26 sealer (Shipper et al. 2005). Others claim that Resilon-treated teeth are strengthened by forming “monoblocks”, which establishes a continuum through bonding of the root filling materials to intraradicular dentin (Teixeira et al. 2004a, 2004b). Conversely, recent data has shown no significant differences in leakage between teeth obturated with gutta percha

Gutta Flow (Coltene/Whaledent, Cuyahoga Falls, OH) is another new material which has been recently introduced to the market. It is a sealer which is composed of a polydimethylsiloxane (silicone) matrix and finely ground gutta percha particles (< 30 \( \mu \text{m} \)). Gutta Flow is dispensed in a paste form and claims to be the first non-heated free-flow gutta percha that does not shrink. Recommended usage is with a master gutta percha cone coated with gutta flow and any remaining space either filled with accessory cones or more paste.

Several unpublished studies have been carried out dealing with Gutta Flow. Two microleakage studies are available using dye penetration and Gutta Flow was found to perform similarly to other commercially available sealers including RoekoSeal, Diaket, and AH Plus (Roggendorf et al. 2001, 2003). Fluid filtration data has also shown Gutta Flow to exhibit similar leakage properties to RoekoSeal and AHPlus when used with gutta percha (Medina et al. 2006 AAE). In another study, the homogeneity and adaptation of Gutta Flow was compared to lateral and vertical condensation of gutta percha. Investigators found that if Gutta Flow was applied with a lentulo, it was well adapted to the canal although the incidence of unfilled areas was higher (ElAyouti et al. 2003).
Purpose

The aim of this in vitro study was to test the null-hypothesis that there is no difference in sealing properties between Resilon/Epiphany sealer, gutta percha/Gutta Flow, and gutta percha/AH26 sealer using the following tests:

1. The coronal to apical (through and through) leakage in bovine incisors obturated using lateral condensation of the 3 experimental materials using a fluid filtration system.

2. Several samples from each group will then be longitudinally sectioned and viewed under Scanning Electron Microscopy (SEM) to assess both adaptation of the materials to the dentin surface and penetration into the dentinal tubules.
MATERIALS & METHODS

Fifty-seven bovine incisors were used for this study. After extraction from cows' jaws the teeth were stored in 0.2% sodium azide in distilled water (Sigma-Aldrich, Steinheim, Germany) for several days before being radiographed with occlusal film (Kodak, Rochester, New York). Desirable teeth were chosen for the study, excluding teeth with canals larger than one-fourth the dentin thickness. Teeth with open apices were also discarded. Soft tissue was removed from the roots with periosteal elevators being careful not to damage the root surface. The crowns of the teeth were removed at the CEJ using a diamond saw (Isomet, Buehler, MI) making standardized roots of 16 mm. Finally, pulp tissues were removed with Hedstrom files (Maillefer, Ballaigues, Switzerland) and the roots stored in 0.2% sodium azide solution at 4°C until use.

Initial coronal flaring was accomplished with Gates Glidden drills (3-6) (Maillefer, Ballaigues, Switzerland). A #15 K-file was introduced into each canal until it was seen just exiting the apical foramen. The working length was determined by subtracting 1.0 mm from this length making the working length approximately 15 mm. Canal instrumentation was accomplished with hand K-files (Maillefer, Ballaigues, Switzerland) and Hedstrom files to a master apical size of 70. Step-back filing was completed with Hedstrom files sizes 80-100 at 1 mm intervals from working length. Two milliliters of 1.25% sodium hypochlorite was used for irrigation between instruments with a 27-guage needle. Canals were then rinsed with 5 milliliters of EDTA (Henry Schein®, Melville, NY) for 1 minute to remove the smear layer before a final rinse with sterile water and complete drying of the canal with paper points prior to root-fillings.
The roots were randomly divided into 1 of 5 groups: 3 experimental groups (15/group), one positive control group (6) and one negative control group (6) as follows:

**Group 1.** Lateral condensation of gutta percha (Premier Dental Products Co., Plymouth Meeting, PA) with AH26 sealer (DeTrey, Zurich, Switzerland). The canal was coated with sealer with a lentulo spiral (Maillefer, Ballaigues, Switzerland). The master gutta percha cone was then coated in sealer and slowly seated to working length. A standardized finger spreader, size B (Maillefer, Ballaigues, Switzerland) and fine-fine accessory gutta percha cones were used for lateral condensation until the canal was completely filled.

**Group 2.** Lateral condensation of Resilon with Epiphany sealer. After drying the canal as previously described, a self etching primer was placed into the canal with a #25 K-file and the excess removed with paper points. Roots were obturated with Resilon and Epiphany sealer in a manner identical to group 1.

**Group 3.** Lateral condensation of gutta percha and Gutta Flow paste in a manner identical to group 1.

**Group 4.** Positive controls were composed of roots filled with gutta percha (3) and Resilon (3) without sealer.
Group 5. Negative controls were filled the same way as positive controls but were completely covered with fingernail varnish (Sally Hansen, Farmingdale, NY), including the apical foramen.

Excess filling material for all groups was removed with a heated #1 Glick instrument and condensed at the canal orifice making a slightly concave surface. Radiographs were taken immediately root filling to ensure complete obturation. The roots were then stored at 37°C and 100% humidity for 1 week prior to testing (Boekel Scientific Incubator). Prior to fluid filtration measurements, control radiographs were taken and each sample with detected voids along the root canal filling was replaced (Figure 16). Roots in groups 1-4 were then covered with clear fingernail varnish excluding the orifice and apical foramen.
FLUID FILTRATION SYSTEM (Figure 1)

Samples were attached to a modification of the fluid filtration apparatus described by Wu et al. (1993b). In this system, positive pressure was provided by a 180 cm column of water at 23° C representing a positive pressure of 17.6 KPa or 0.176 atmospheres. Before testing, the system was flushed to ensure that there was no air bubbles trapped in the tubing. Prior to testing, clear acrylic cylinders were made with an 18-guage needle running throughout the acrylic using an empty prophy paste carrier as a stent. One end of the needle remained flush with the acrylic and this is where the root was attached and the other end of the needle protruded 20 mm from the block and attached the sample to the fluid filtration system (Figure 2). The coronal portion of each sample was attached to the acrylic platform with cyanoacrylate (Henkel Consumer Adhesives, Avon, OH) and polyurethane glue (The Gorilla Glue Co., Cincinatti, OH) to provide a fluid tight seal (Figure 17). An air bubble of approximately 3 mm in length was introduced into the system and its movement controlled by a micro syringe. Once each sample was connected to the filtration device and secured with orthodontic wire the system was opened and allowed to calibrate for 5 minutes. The movement of the air bubble introduced previously was then measured for 5 minutes and the amount of leakage in microliters was read from the micro syringe. Each sample was measured twice and the average value in microliters was computed. Positive and negative controls were connected to the system before any experimental groups to make sure the system was functioning properly.
Measurement of Area Exposed to Fluid Flow (Figure 18)

After leakage measurements samples were removed from the acrylic platforms. For precise measurement and analysis of the surface areas of canal orifices, a digital-imaging system consisting of a desktop flatbed scanner (Hewlett-Packard ScanJet 4p, Hewlett-Packard, Cupertino, CA) and digital image analysis software (NIH/SCION Image Release Beta 3b for Windows, National Institutes of Health, Bethesda, MD) were used. In brief, the procedures used are as follows: Digital pictures were taken of each canal orifice from a coronal direction with a Fuji Film Fine Pix S2 Pro and Nikon F-Mount Lens (Fuji Photo Film Co. Ltd., Japan) at known magnification and distance. Images were then scanned at 300 dpi into a digital format using a desktop scanner with HP DeskScan II software. The scanned images were saved as TIFF files. Adobe Photoshop 5.0.2 (Adobe Systems Incorp., San Jose, CA) was used to produce gray-scale images and the data in pixels were converted to millimeters. Once the unit was selected, the surface area was traced by using the tools options. The surface area was then calculated by selecting the “measurement” option (from the analyze menu). To compare the accuracy and precision of area measurement, three separate tracings were conducted and a mean area was calculated.
Scanning Electron Microscopy (SEM)

After areas were calculated, 3 samples from each group were chosen for SEM examination. Samples which displayed the highest amount of leakage, the lowest amount of leakage, and an average amount of leakage were chosen for the analysis. Two longitudinal grooves were made with a diamond disc and the roots were split with a mallet and chisel to expose the filling-root dentin interface (Figure 19). One half of each root was subsequently sectioned into coronal, middle, and apical thirds. Each section was mounted onto an SEM specimen stub and coated with gold/palladium film with a sputter coater (Polaron E52000, Watford, Hertfordshire, England). Specimens were viewed with a scanning electron microscope (JEOL JSM 6320, Tokyo, Japan) at 3 kV accelerating voltage and between 33x-1500x magnification to produce digital images.

Images for each group were than viewed and characterized according to the adaptability of filling materials with the dentinal surface. The depth of penetration of the individual sealers into dentinal tubules was also observed.
Materials tested

Gutta percha

Gutta percha 19-22%
Wax/resin 1-4%
Barium sulphates 1-17%
Zinc oxide 60-75%

AH26

Powder

Bismuth oxide 60%
Hexamethylenetetramine 25%
Silver powder 10%
Titanium oxide 5%

Liquid

Epoxybisphenol-resin 100%

Gutta Flow

Gutta percha powder (< 30 μm particle size)
Addition cross-linking polydimethylsiloxane

Resilon

Epiphany Points

Compound of polyester, difunctional methacrylate resin, bioactive glass, radiopaque fillers and coloring agent
Epiphany Primer

Acidic monomer solution in water

Epiphany Thinning Resin

EBPADMA resins, photo initiator, amines, stabilizer and Red #40

Epiphany Root Canal Sealer

Mixture of UDMA, PEGDMA, EBPADMA & BISGMA resins, silane-treated bariumborosilicate glasses, aluminum oxide, barium sulfate, silica, calcium hydroxide, bismuth oxychloride with amines, peroxide, photo initiator, stabilizers and pigment
DATA ANALYSIS

Initial data was recorded in microliters (μl) and then converted to hydraulic conductance (μl cm⁻¹ min⁻¹ cm⁻¹ H2O) by the following formula: \( L_p = \frac{J_v}{\Delta P} \times T \times A \), where \( J_v \) is the volumetric fluid flow (in μl), \( \Delta P \) the pressure difference per gradient in 180 cm column of the solution (in cm H2O), \( A \) the frontal area available for fluid transport (\( \pi r^2 \) in cm²) and \( T \) the time (in min). Descriptive statistics were performed on the data to obtain means and standard deviations of each group. Statistical analysis was performed using the Kruskal-Wallis test for nonparametric data to determine whether there were significant differences between groups. Pairs of groups were compared using the Mann-Whitney U test (\( P < 0.05 \)).
Results

Means and standard deviations for microleakage (μl), orifi area (cm²), and hydraulic conductance (μl cm⁻¹ min⁻¹ cm⁻¹ H₂O) for each group are shown in Tables 1-3 and Figures 3-5 respectively. The leakage of the negative controls were all uniformly zero, and the leakage of the positive controls were all immeasurably high. The Resilon/Epiphany group recorded the smallest hydraulic conductance (1.08 x 10⁻⁵ μl cm⁻¹ min⁻¹ cm⁻¹ H₂O), followed by the Gutta Percha/Gutta Flow (1.41 x 10⁻⁵ μl cm⁻¹ min⁻¹ cm⁻¹ H₂O) and the Gutta Percha/AH26 groups (1.46 x 10⁻⁵ μl cm⁻¹ min⁻¹ cm⁻¹ H₂O). No statistically significant differences were found between groups with respect to mean orifi area (p=0.41).

The Kruskal-Wallis test indicated that differences in hydraulic conductance between the groups was statistically significant (P = 0.038). The Mann-Whitney U test was used to compare individual groups and it was found that the Resilon and Gutta Flow groups’ differences were statistically significant (p = 0.012), while the AH26/Gutta Flow (p = 0.51) and AH26/Resilon (p = 0.085) groups’ differences were not.

Scanning Electron Microscopy (SEM) revealed gap formation in all groups. Resilon displayed good adaptation to Epiphany sealer but showed some gap formation between Epiphany sealer and dentin (Figures 6-8). AH26 showed gaps mainly between the sealer and gutta percha although isolated gaps were also observed between dentin and sealer (Figures 9-11). Gutta Flow showed the least adaptation of all groups and gaps were seen between both sealer and dentin and between sealer and gutta percha (Figures 12-14). No group showed sealer penetration into dentinal tubules.
Discussion

Various techniques have been used in the past to assess the leakage of endodontic materials. Studies have used dyes, radioisotopes, bacteria, electrochemical methods, and fluid-filtration. When evaluating a new root filling material, comparison of its sealing ability to known products through leakage studies is still considered important. The use of adhesive root canal sealers which may bind to both dentin and the core material may play an important role in minimizing endodontic leakage and must be examined for their ability to accomplish this task.

Many different materials have been proposed as root canal fillings, but none have replaced gutta percha, which is universally accepted as the gold standard for filling root canals. Although widely used, many feel that gutta percha is the weak link in endodontic therapy (Khayat et al. 1993, Trope et al. 1995). Recently, a new synthetic polyester polymer containing methacrylate resins has been introduced as a replacement for gutta percha. Resilon has similar handling and clinical properties as gutta percha, yet manufacturers claim it provides a superior seal compared to conventional gutta percha techniques. Another new material has also been introduced to the market recently. Gutta Flow is a silicon-based sealer which contains small gutta percha pieces (< 30 µm). Manufacturers claim that Gutta Flow is the first free-flow gutta percha which does not shrink.

In this study, a modified version of the original fluid-filtration model (Wu et al. 1993b) was used to determine the coronal to apical sealing ability of Resilon/Epiphany sealer and gutta percha/Gutta Flow sealer and compared with gutta percha/AH 26 sealer. The Resilon group showed the lowest amount of hydraulic leakage compared to the Gutta
Flow and AH26 groups (Figure 5). The Kruskal-Wallis test was used to determine that there was a significant difference between groups (p = 0.038). When individual groups were compared using the Mann-Whitney U test, only the Resilon and Gutta Flow groups’ differences were statistically significant (p = 0.012). One would have expected the Resilon and AH26 groups to display a significant difference based on their hydraulic conductance values, but this was not the case (p = 0.085), due in part to the high standard deviation of the AH26 group (Figure 3). High standard deviations are common in leakage studies (Cobankara et al. 2002, 2004) because it is difficult to precisely standardize all samples and to obturate all roots exactly the same. In addition, the AH26 group displayed the largest mean area exposed to fluid flow, which could have led to higher leakage values, although these differences were not statistically significant (Figure 4).

Fluid filtration was used in this study because researchers have found that it is a more sensitive method for determining leakage along root fillings than bacterial methods (Wu et al. 1993b) and dye penetration methods (Wu et al. 1994a, Camps & Pashley 2003). This technique uses positive pressure to rid the sample of entrapped air, thus making detection of true voids more accurate (Oliver & Abbott 1991, Spangberg et al. 1989). Fluid filtration is also quick, inexpensive, non-destructive, repeatable, and supplies volumetric quantitative leakage data. One potential limitation of the fluid filtration technique is its inability to detect partial or cul-de-sac type voids.

Fully developed bovine incisors were used for this study and their root lengths and apical sizes were standardized in order to reduce the variability between groups. Bovine teeth have been shown to be suitable substitutes for human teeth in the adhesion
testing of cements and composite resins (Nakamichi et al. 1983). Root canal sealers have also been shown to provide strong bonds to bovine dentin (Wennberg & Ørstavik 1990) and these measurements are in close agreement with earlier adhesion measurements on human coronal dentin (Ørstavik et al. 1983). Dentinal tubules in bovine teeth are also of similar size, morphology, and density to those of human teeth (Haapasalo & Ørstavik 1987). Therefore, bovine incisors were considered a viable substitute for human teeth in this study.

The use of hand instrumentation and lateral condensation was used in this study because it has been practiced as an effective technique for many years and has shown high success rates in various clinical trials (Sjögren et al. 1990, Kerekes & Tronstad 1979). Because AH26 is a commonly used epoxy resin-based sealer which has been shown to provide an adequate seal (Wu et al. 1995, Wu et al. 2004, Limkangwalmongkol et al. 1991, Ford 1979) and display high bond strengths to both dentin and gutta percha (Ørstavik et al. 1983, Wennberg & Ørstavik 1990), this sealer was used as a comparison for the two new root filling materials.

This study is in agreement with previous studies which have shown no statistically significant differences in leakage between gutta percha and AH Plus or Kerr sealers and Resilon and Epiphany sealer (Tay et al. 2005, Hanson et al. 2006 abstract, Goldberg et al. 2006 abstract). In another study, gutta percha and AH Plus leaked significantly less to fluid filtration than Resilon and Epiphany sealer at 1 week, yet no differences were found at 2 and 3 weeks (Suhler et al. 2006 abstract). Conversely, other studies have found gutta percha and AH26 sealer to leak significantly more than Resilon and Epiphany sealer (Shipper et al. 2004, 2005). Thus, conflicting results are appearing
concerning the sealing abilities of Resilon and long-term follow-up studies should be
carried out to assess Resilon’s true clinical efficacy.

Very little published information is available for Gutta Flow, but this sealer has
shown similar sealing properties to RoekoSeal, Diaket, and AH Plus (Roggendorf et al.
2001 & 2003, Medina et al. 2006). Gutta Flow is composed of small gutta percha pieces
(< 30 µm) and polydimethylsiloxane, a silicon-based organic polymer. It is very similar
to Roekoseal, another silicon-based sealer, which has shown similar sealing properties to
AH26 (Cobankara et al. 2004) and better sealing properties than Pulp Canal Sealer,
Topseal, and EndoRez (Wu et al. 2002, Bouillaguet et al. 2004). Cobankara’s findings
are in agreement with this study which showed the Gutta Flow and AH26 groups to have
similar leakage values.

Scanning Electron Microscopy (SEM) revealed that Epiphany sealer shows good
adaptation to both Resilon and dentin, but some gaps were seen at the sealer/dentin
interface. In addition, very little penetration into the dentinal tubules was seen. These
findings are in disagreement with Shipper et al. (2004) who found no gaps between
Resilon/Epiphany and dentin using SEM. In contrast, specimens in their study showed
sealer penetration into dentinal tubules which is probably attributed to heat and pressure
applied during vertical condensation. SEM micrographs of AH26 and gutta percha
showed good adaptation of sealer to dentin, although some gap formation was seen at the
AH26/sealer interface. Also, relatively poor adhesion between AH26 and gutta percha
was observed. This is in agreement with other studies which have shown gaps at the
AH26/Gutta percha interface (Tay et al. 2005). Gutta Flow showed the worst adaptation
to both gutta percha and dentin. Gutta percha was seen almost devoid of any sealer and
numerous gaps were seen between the sealer and dentinal surfaces. These gaps could have accounted for the higher leakage values in this group.

Tay and colleagues (2005) have questioned the apical adaptability of Resilon/Epiphany sealer shown by Shipper et al. (2004). They found gaps at the sealer/dentin interface in roots filled with both Resilon/Epiphany sealer and gutta percha/AH Plus sealer using SEM (Tay et al. 2005). Using Transmission Electron Microscopy to assess silver penetration, authors showed that the weak link in the Resilon specimens was at the sealer/dentin interface, while the AH26 group displayed more gaps at the sealer/gutta percha interface. This may be explained by polymerization contraction of the methacrylate-based resin sealer (Davidson & DeGee 1984, Bouillaguet et al. 2003) and a relatively weak bond between AH 26 and gutta percha.

The long-term stability of Resilon has also been questioned. A recent study has shown that Resilon is susceptible to enzymatic hydrolysis (Tay et al. 2005). Resilon, gutta percha, and polycaprolactone disks were incubated in saline, lipase PS or cholesterol esterase. Gutta percha showed weight gains to all three solutions while Resilon and polycaprolactone disks exhibited extensive surface thinning and weight lossess after incubation in both bacterial enzymes. It is well known that polycaprolactone, a polyester and main ingredient in Resilon, is subject to degradation by cleavage of its ester bonds (Gan et al. 1997, Lefévre et al. 2002). Therefore, the integrity of the seal produced by Resilon may be compromised if exposed to bacteria which can produce enzymes that effectively cleave its ester bonds. This hypothesis has been tested clinically at 12- and 18- month follow-ups of teeth treated with Resilon/Epiphany sealer;
root fillings have shown no signs of radiographic degradation (Debelian 2006, Heffernan et al. 2006).

Although fluid filtration techniques are generally considered the gold standard for measuring endodontic leakage, many authors still question the validity and clinical relevance of leakage results. One study showed a poor correlation between dye, electrochemical, bacterial, and fluid filtration techniques for evaluating leakage of root canal fillings (Karagenc et al. 2006). Other studies have shown fluid filtration to be more sensitive for detecting leakage than both dye and bacterial penetration (Camps & Pashley 2003, Wu et al. 1993b, Wu et al. 1994a).

The increased sensitivity in detecting root filling leakage seen with the fluid filtration technique is probably due to a combination of two factors. The first is the fact that it uses positive pressure to measure the volume of fluid that will move through complete gaps in the root filling. Conversely, dye or radioisotopes penetrate as a function of capillary action or passive diffusion of the tracer which are affected by diameter of the void, hydrophobicity of dentin/filling materials, and concentration/diffusion coefficient of the tracer (Wu et al. 1993b). Another reason for increased sensitivity in testing leakage using fluid filtration is the size of the tracer used. For example, water molecules ($10^{-3}$ $\mu$m) are several orders of magnitude smaller than both conventional dyes and bacteria (1-5 $\mu$m).

While clinical studies have shown success rates for root canal therapy over 90% (Sjogren et al. 1990, Kerekes & Tronstad 1979), all root filling materials have been shown to leak in-vitro, regardless of the technique used. Thus, correlation is lacking between the ability of materials to seal in-vitro and the tissue response which is seen in-
vivo. Therefore, future research should improve leakage methodology and determine what impact hydraulic leakage has on the immediate and long-term success of endodontic treatment. Also, in-vitro studies should continue to be utilized as screening tools for evaluating new materials.

Within the limitations of this study, there was a definite trend toward better sealing properties in the Resilon group as compared to the AH26 and Gutta Flow groups. Some attribute the excellent sealing ability of Resilon to the "monoblock" that is created by the adhesion of the Resilon cone to the Epiphany sealer, which adheres and penetrates into the dentin walls of the root canal system (Texeira et al. 2004); although very little tubular penetration was observed in this study. The use of Resilon may decrease coronal leakage through a defective temporary or permanent restoration and possibly increase success rates of endodontic therapy. This theory was tested in dogs and it was found that teeth obturated with gutta percha/AH 26 displayed 60% more histologic inflammation than teeth obturated with Resilon/Epiphany sealer after intentional bacterial inoculation of the root fillings for 14 weeks (Shipper et al. 2005).

Gutta Flow displayed similar leakage values to AH 26 in this study. This is in agreement with a previous study which showed RoekoSeal, another silicone-based sealer, but without gutta percha, to have similar sealing properties to AH 26 (Cobankara et al. 2004). The addition of gutta percha particles to the polydimethylsiloxane matrix does not seem to improve the sealing properties of this material. Therefore, the claim by the manufacturers that Gutta Flow is the first free-flowable gutta percha that does not shrink is misleading and may not be clinically relevant.
Overall, Resilon and Epiphany sealer showed good adaptation to each other and to the dentinal walls, although some gaps were observed at the sealer/dentin interface. This may be explained by polymerization shrinkage of the methacrylate-based resin sealer. AH 26 and Gutta Flow showed poorer adaptation to gutta percha than Epiphany did to Resilon and this may have accounted for the increased leakage seen in these groups. Although Resilon appears to be a promising new material for filling root canals, further studies are needed to assess both its long-term seal and structural integrity. Recently, short-term clinical results have shown no degradation of Resilon root fillings determined radiographically and that successful outcomes measured at 12-18 months are similar to those reported in previous university-based studies (Heffernan et al. 2006 abstract, Debelian 2006 abstract). These findings suggest that Resilon and Epiphany sealer could be used as an alternative to gutta percha and conventional sealers, but long-term data is needed before gutta percha is completely replaced.
Conclusions:

1. Resilon and Epiphany sealer displayed lower leakage values than AH 26/Gutta percha and Gutta Flow/Gutta Percha and this may be due to its superior adhesion between core material and sealer.

2. Gap formation was seen in all groups, suggesting a complete fluid-tight seal of the root canal space may not be possible.

3. Long-term in-vitro and in-vivo data is needed before gutta percha is replaced by Resilon or any other new material.
Appendix

TABLE 1. Fluid Filtration Measurements (µl)

<table>
<thead>
<tr>
<th>Samples</th>
<th>GP/AH26</th>
<th>Resilon</th>
<th>GP/Gutta Flow</th>
</tr>
</thead>
<tbody>
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<td>0.009</td>
<td>0.0065</td>
<td>0.0115</td>
</tr>
<tr>
<td>2</td>
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</tr>
<tr>
<td>3</td>
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<td>0.0095</td>
</tr>
<tr>
<td>4</td>
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<td>0.0085</td>
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<td>0.0105</td>
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</tr>
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<tr>
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TABLE 2. Areas of orif of the Root Samples (cm$^2$)

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<th>GP/Gutta Flow</th>
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<td>GP/Gutta Flow</td>
</tr>
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<td>---------------</td>
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<td>1.07E-05</td>
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<tr>
<td>2</td>
<td>1.17E-05</td>
<td>9.79E-06</td>
<td>1.66E-05</td>
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<td>3</td>
<td>1.96E-05</td>
<td>1.07E-05</td>
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<td>4</td>
<td>2.48E-05</td>
<td>1.47E-05</td>
<td>1.73E-05</td>
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<td>5</td>
<td>1.10E-05</td>
<td>1.37E-05</td>
<td>6.99E-06</td>
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<tr>
<td>6</td>
<td>1.43E-05</td>
<td>6.54E-06</td>
<td>1.92E-05</td>
</tr>
<tr>
<td>7</td>
<td>1.28E-05</td>
<td>1.36E-05</td>
<td>1.01E-05</td>
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<tr>
<td>8</td>
<td>1.16E-05</td>
<td>9.25E-06</td>
<td>8.67E-06</td>
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<tr>
<td>9</td>
<td>1.23E-05</td>
<td>9.76E-06</td>
<td>1.69E-05</td>
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<tr>
<td>10</td>
<td>9.31E-06</td>
<td>5.41E-06</td>
<td>1.71E-05</td>
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<tr>
<td>11</td>
<td>3.75E-05</td>
<td>1.39E-05</td>
<td>1.48E-05</td>
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<tr>
<td>12</td>
<td>5.82E-06</td>
<td>1.06E-05</td>
<td>1.63E-05</td>
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<tr>
<td>13</td>
<td>1.35E-05</td>
<td>9.49E-06</td>
<td>1.24E-05</td>
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<td>14</td>
<td>1.42E-05</td>
<td>1.25E-05</td>
<td>1.77E-05</td>
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<tr>
<td>15</td>
<td>7.04E-06</td>
<td>1.01E-05</td>
<td>1.44E-05</td>
</tr>
</tbody>
</table>

**Mean**

|   | 1.46E-05 | 1.08E-05 | 1.41E-05 |

**SD**

|   | 7.82E-06 | 2.65E-06 | 3.73E-06 |

* Representing the degree of microleakage per unit area, penetrated between the dentin and sealer, the sealer and filling material, or diffused within the dentin, the sealer and/or the filling material.
FIGURE 1. Hydraulic Conductance (Pashley) System
FIGURE 2. Schematic Assembling of the Root Sample Attached to the Stand
FIGURE 3. Fluid Filtration Measurements (μl)

<table>
<thead>
<tr>
<th>Group</th>
<th>Fluid Flow in μL min</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>GP AH26</td>
<td>0.012167</td>
<td>0.00677</td>
</tr>
<tr>
<td>Resilon</td>
<td>0.007867</td>
<td>0.00127</td>
</tr>
<tr>
<td>GP Flow</td>
<td>0.011167</td>
<td>0.00262</td>
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</tbody>
</table>
FIGURE 4. Areas of orifi of the Root Samples (cm²)

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>GP</td>
<td>0.973467</td>
<td>0.2688</td>
</tr>
<tr>
<td>Resilon</td>
<td>0.857013</td>
<td>0.23615</td>
</tr>
<tr>
<td>GP Flow</td>
<td>0.91118</td>
<td>0.1897</td>
</tr>
</tbody>
</table>
FIGURE 5. Hydraulic Conductance ($\mu$L cm H$_2$O$^{-1}$ min$^{-1}$ cm$^{-2}$)

<table>
<thead>
<tr>
<th>Group</th>
<th>GP AH26</th>
<th>Resilon</th>
<th>GP Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1.46E-05</td>
<td>1.08E-05</td>
<td>1.41E-05</td>
</tr>
</tbody>
</table>

* Denotes significance at p<0.05
FIGURE 6 (A-B). SEM Micrographs (Resilon + Epiphany)
FIGURE 7 (A-B). SEM Micrographs (Resilon + Epiphany)
FIGURE 8 (A-B). SEM Micrographs (Resilon + Epiphany)
FIGURE 9 (A-B). SEM Micrographs (Gutta Percha + AH26)
FIGURE 10 (A-B). SEM Micrographs (Gutta Percha + AH26)
FIGURE 11 (A). SEM Micrographs (Gutta Percha + AH26)
FIGURE 12 (A-B). SEM Micrographs (Gutta Percha + Gutta Flow)
FIGURE 13 (A-B). SEM Micrographs (Gutta Percha + Gutta Flow)
FIGURE 15 (A-B). Control Radiographs for Selection of Samples

Image A shows two sets of teeth with labeled points - yellow points indicate qualified selected teeth, and red points indicate disqualified teeth. Image B displays a row of teeth with yellow and red points similarly distinguished as qualified and disqualified.
FIGURE 16. Quality Control of the Root Canal Samples

Obturated Lateral Canal
FIGURE 17 (A-B). The Sample Assembly Ready to Attach to the HC System
FIGURE 18. The Surface Area of the Canal Orifice of each Root Sample was calculated

Images of different canal orifi with various Areas Exposed to Fluid Flow

Roots removed from Acrylic Platforms

Area exposed to Fluid Flow Computed with a Digital Images Analysis Software*

* Fuji Film Fine Pix S2 Pro Camera with a Nikon F-mount Lens

** NIH/SCION Image-Release Beta 3b for Windows
FIGURE 19. The Split Root Samples Ready for Preparation for SEM Analysis of the Root Canal Obturations
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