EDITORIAL

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Sealing and Obturation Techniques – Critical Overview

Techniki uszczelniania i wypełniania kanałów korzeniowych – przegląd piśmiennictwa

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Abstract

Successful root canal therapy requires a meticulous chemomechanical cleaning and shaping in order to obtain a three-dimensional obturation of the root canal system. All materials recommended for root canal filling have advantages and disadvantages and there is not a material or a method available so far that fulfills all possible requirements. For instance, there is not a unique and generally accepted method, for the delivery of gutta-percha to the canal. Filling the root canal with cold or warm gutta-percha without a sealer results in increased apical leakage regardless of the obturation technique used. Studies dealing with the effect of different root canal sealers on apical dye penetration after obturation with different systems are available, but their results remain controversial because of the variability of the methods used to evaluate the different systems. This paper presents a detailed overview of those studies (**Dent. Med. Probl. 2005, 42, 1, 11–19**).

Key words: dental anatomy, root filling, thermoplastic obturation, sealers.

Streszczenie

Skuteczne leczenie endodontyczne wymaga skrupulatnego mechaniczno-chemicznego opracowania kanałów korzeniowych i takiego ukształtowania, aby uzyskać ich wypełnienie w trzech wymiarach. Wszystkie materiały zalecane do wypełniania kanałów mają zalety i wady, i dlatego nie istnieje omnipotentna metoda lub materiał w leczeniu endodontycznym. Na przykład nie ma jednej i powszechnie akceptowanej metody aplikowania gutaperki do kanału. Wypełnianie kanału zimną lub ciepłą gutoperką, bez użycia uszczelniacza, prowadzi do przepełnienia, niezależnie od zastosowanej techniki wypełniania. Wykonano wiele badań dotyczących wpływu różnych uszczelniaczy kanałowych na wierzchołkową penetrację barwnika po wypełnieniu, lecz ich wyniki pozostają kontrowersyjne z powodu różnic metod stosowanych do oceny poszczególnych systemów. Praca ta prezentuje szczegółowy przegląd tych badań (**Dent. Med. Probl. 2005, 42, 1, 11–19**).

Słowa kluczowe: anatomia zębów, wypełnianie kanałów, kondensacja, termoplastyka gutaperki, uszczelniacze.

The purpose of the endodontic filling is to obtain a hermetic seal of the root canal using sealer materials with adequate biological and physicochemical properties, thus eliminating the risks of infection or reinfection of the root canal system [1]. To this end, the shape of the root canal filling materials must be selected on the basis of a critical evaluation of the presented evidence. All materials recommended for root canal filling have advantages and disadvantages and there is not a material or a method, available so far, that fulfills all possible requirements. Currently, the material of choice to obturate the prepared root canal space is gutta-percha, which has to be compacted and used together with sealers. However, there is not a unique, generally accepted, method for the delivery of gutta-percha to the canal. For this purpose, four basic techniques exist: the cold compactation of gutta-percha; the compactation of gutta-percha that has been heat-softened in the canal and then cold compacted; the compactation of gutta-percha which has been thermoplasticized, injected into the system, and then cold compacted; and the compactation of gutta-percha that has been placed in the canal and softened through mechanical means [2].

Filling the root canal with cold or warm gutta-percha without a sealer results in increased apical leakage regardless of the obturation technique used [3]. Hence, the root-canal sealer has a crucial importance with regard to the long-term results of the root-canal filling, because a sealing material is needed to adhere the gutta-percha to the root-canal dentin and to fill irregularities [4].

A hermetic seal cannot be obtained without the use of a sealer which forms a fluid-tight seal and barrier between the dentin and gutta-percha apically, laterally, and coronally. The dimensional stability of root canal sealers is relevant for an appropriate function of the root filling. For decades, a number of different formulations of sealer cements have been used in conjunction with gutta-percha which has been considered the most adaptable and compatible core material for root fillings [5].

Sealers comprise a heterogeneous group of materials with different compositions. Many types and brands of endodontic sealers are available commercially, that can be classified according to their chemical composition. There are sealers composed by zinc oxide and eugenol based on various adaptations of Grossman or Rickert's formulas [6]; epoxy resin based sealers, used for many years with clinical success [7]; calcium hydroxide, introduced in the 1980s to stimulate hard tissue formation for apical closure [8]; and glass ionomer based sealer which may be spontaneously bond to dentin walls at the apex [9]. None of the presently available materials satisfies fully the requirements for an hermetic three-dimensional obturation of the root canal system. Microleakage, whether from an apical [10] or a coronal direction [11], remains a clinical problem and a possible source of failure [12]. It is defined as the passage of bacteria, fluids, and chemical substances between the root structure and filling of any type.

The dimensional stability of root canal sealers is relevant for an appropriate function of the root filling. It is well known that microleakage between the root-canal filling and root-canal walls may adversely affect the results of root-canal treatment [13]. Microleakage in root canals is complicated as many variables may contribute, such as the anatomy and instrumented size of the root canal, the irrigating solutions, the root filling techniques, the infectious state of the canal and the physical and chemical properties of the sealer [14]. Dimensional changes of root canal sealers over time may introduce gaps and channels along the filling material and the tooth, which may be large enough to permit microorganisms to pass along the spaces. Positive controls in sealability studies consist of obturation without a sealer, resulting in extensive leakage [15, 16].

Several investigations have been carried out with different methods to assess the mechanical and biological properties of different sealers [17–20]. As shown in Table 1 those studies include: coloured dye penetration [21], bacterial leakage [22], radiolabelled penetration [23], dissolution of hard tissue [24], clearing of teeth [25] spectrometry of radioisotopes [26], electrochemical methods [27] and gas chromatography [28]. So many endodontic tests may be difficult to standardize [29] and the results are difficult to reproduce and compare [30]. The variety of evaluative methodologies and their assessment parameters are the major reasons for such disagreement. However, leakage studies on the sealing properties of endodontic materials are important and necessary.

A clear, reproducible, quantitative comparison of obturating methods and, or, materials is valuable to the clinician in predicting the likely behavior of the obturation. In view of the large number of leakage studies published, it seems generally accepted that the evaluation of the leakage of particles or solutions between a root filling and the root canal wall is a suitable method to ascertain whether a root canal filling fulfills its purpose [30]. Therefore, the evaluation of the quality of a root canal filling using leakage tests is still relevant. For authors like Canalda-Sahli et al. [31], the greatest value of the apical seal test is the ability to establish comparisons between different techniques and materials and that it is sufficient to evaluate them in term. Scuurs et al. [32] conclude that the value of many endodontic leakage studies is limited because of the low power of the statistical tests applied, due to the fact that sample sizes are too small.

The fluid filtration method is based on a liquid which is forced through the sealer or within the voids existing between the sealer, the dentin walls, and the gutta-percha. Therefore the results may follow the laws governing the phenomena of filtration, such as the Poiseuille-Hagen equation, and may be modified by factors like the applied pressure or the measurement time [33]. For some authors, fluid filtration studies present several advantages over dye diffusion studies [30]. This system, first described by Derkson et al. [34], was then designed to evaluate the sealing properties of temporary filling materials by Pashley et al. [35] and was modified by Wu et al. [30] for endodontic leakage studies. The results are automatically

Table 1. Studies to assess the properties of different sealers

Tabela 1. Badania nad właściwościami różnych uszczelniaczy kanałów korzeniowych

Authors (Autorzy)	Nº samples (Liczba próbek)	Sealer (Uszczelniacz)	Experimental group (Grupa badana)	Microleakage measurements (Pomiar mikro-przecieku)	Year (Rok)
Gilbert et al.	70	Roth 801	lateral compactation Thermafil vertical compactation	bacterial leakage dye penetration	2001
Beatty et al.	80	Roth 801	single cone lateral compactation Ultrafil Thermafil	dye penetration	1989
Lares et al.	60	Kerr	lateral compactation Thermafil	dye penetration	1990
Oguntebi et al.	120	Roth 801 Sealapex Lee Endofil AH26 Ketac-cem	Thermafil	dye penetration	1992
McMurtrey et al.	22	Roth 801	lateral compactation Thermafil	dye penetration	1992
Dummer et al.	150	Tubliseal	lateral compactation Thermafil	dye penetration	1993
Gençoglu et al.	128	Grossman	lateral compactation Ultrafil Thermafil	dye penetration	1993
Saunders et al.	144	Ketac Endo	Thermafil lateral condensation	dye penetration	1994
Bhambhani et al.	50	Thermaseal Kerr	Thermafil lateral condensation	dye penetration	1994
Kytridou et al.	51	Sealapex	Thermafil System B	dye penetration	1999
Abarca et al.	22	Top Seal	Thermafil lateral condensation	dye penetration	2001
Gençoglu et al.	100	Kerr	lateral compactation Thermafil Quick-Fill System B	dye penetration	2002
Schafer et al.	284	Roekoseal AH plus AH26	lateral compactation Thermafil	dye penetration	2002
Boussetta et al.	64	Sealite regular	Herofill lateral condensation thermomechanical	dye penetration	2003
Dalat et al.	79	AH26	single cone lateral condensation Thermafil Ultrafil vertical condensation	dye vacuum tracing	1994
Yared et al.	90	Kerrs	System B	fluid filtration	1995
Pommel et al.	50	?	single cone lateral condensation Vertical condensation Thermafil System B	fluid filtration	2001
Pommel et al.	36	Sealite	Thermafil	fluid filtration	2001
Baumgardner et al.	64	Roth	lateral compactation Thermafil lateral + vertical compactation	linear leakage volumetric penetration	1995
Haddix et al.	100	zinc oxide-eugenol	lateral compactation Thermafil Thermafil twist-off	spectrophotometric	1991

recorded, thus eliminating any operator bias. The results are very accurate because the smallest recordable volume is 1.92×10^{-9} l. In addition, unlike the clearing studies [36], there is no modification of the seal because the measurements are made directly after filling without dipping the roots in acids, alcohol or methyl salicylate. A major advantage of the method is the ability to measure microleakage without destroying the root specimens. Wu et al. [30], observed that data obtained from the linear measurement of dye penetration after longitudinal splitting or decalcification and clearing of roots varied much more than data obtained after cross-sectioning of the samples. They also emphasized that these methods did not produce relevant and reliable semiquantitative data, because these techniques did not provide any information about the volume of the tracer that penetrated along the root canal obturation. Radioisotope labelling, and the bacterial leakage method are less frequently used because they require sophisticated materials. Because none of them reproduces the complex mechanisms that lead to a periapical infection, all of these techniques have some value [37]. The electrochemical method is based on the diffusion of ions through very narrow spaces, and the outcome of this method likely depends on electrical laws. Thus the lack of correlation is not surprising because correlation implies a phenomenon governed by electrical, filtration and diffusion laws at the same time [38]. Pommel et al. [38] compared three methods of evaluation of the apical seal, each successively used on the same teeth: a fluid filtration method, an electrochemical method, and a dye penetration study. They reported no correlation among the results obtained with three methods of evaluation. The dye leakage evaluation is the most commonly used technique, probably because this is the simplest method to carry out the study. Roig et al. [39] showed that dye leakage studies are sufficiently valid, provided that the experimental conditions are standardized, including the type of dye used, the duration of sample immersion in the dye solution, and the application or not of thermal cycling procedures during the experiment. The clearing technique facilitates the observation of the relation between the sealing material and the apical foramen. Even though there is no evidence that demonstrates the amount of leakage a root canal must exhibit before being clinically detrimental, some studies have shown that microleakage adversely affects the success of root canal therapy [40, 41]. Thus, the passage of microorganisms and their toxins in the periradicular tissues can induce inflammation in the periradicular tissues [42, 43] and consequently reduce the success rate of the root canal therapy.

The data available are sometimes not comparable (see Tab. 2), making it difficult for the reader to build an opinion. Kazemi et al. [44] used a volumetric technique to study dimensional changes in sealers based on epoxy resin, zincoxide-eugenol (ZnOE) and silicone based material. They found that the largest and most rapid dimensional changes occurred with ZnOE-based sealers, the least and slowest with the silicone-based material. Smith and Steiman had compared the apical seal of the Ketac-Endo® (Espe GmbH, Seefeld, Germany) a glass ionomer root canal sealer with three zincoxide-eugenol based sealers using lateral condensation and found that Ketac-Endo® leaked the most [45].

Some studies report the marginal seal of resin-based cements to be superior to that of other cements [46]. In contrast, other studies have shown that a calcium hydroxide-based sealer Sealapex® (Kerr Mfg. Co) provides a significantly better seal than others, including resin-based cements [47]. Özata et al. [48] observed more leakage in Ketac-Endo and significant differences between Ketac-Endo and Apexit® (Vivadent, Schann, Germany) a calcium hydroxide contain-

Table 2. Studies dealing with the effect of canal sealers on apical microleakage

Tabela 2. Badania nad wpływem uszczelniaczy kanałowych na mikroprzeciek wierzchołkowy

Authors (Autorzy)	Nº Samples (Liczba próbek)	Sealers (Uszczelniacze)	Microleakage measurements (Pomiar mikroprzecieku)	Year (Rok)
Miletic et al.	60	AH26, AH Plus, Diaket, Apexit, Ketac-Endo	air bubble in a capillary tube	2002
Chailertvanitykul et al.	80	AH26, Apexit, Tubliseal, EWT	bacterial leakage	1996
Smith et al.	54	Ketac-Endo, Tubliseal (old formula), Tubliseal (new formula), Roth 801	dye leakage/clearing method	1994
Roig et al.	45	Apexit, Ketac-Endo, Sealapex, Endomethasone	dye leakage/clearing method	1996
Madison et al.	64	Roth, AH26, Sealapex	dye penetration	1988
Limkangwalmongkol et al.	50	Apexit, Sealapex, Tubliseal, AH26	dye penetration longitudinal sectioning	1992
Limkangwalmongkol et al.	125	Apexit, Sealapex, Tubliseal, AH26	dye penetration transverse sectioning	1991
Saunders et al.	60	Vitrebond, Tubliseal	dye penetration transverse sectioning	1992
Cobankara et al.	40	AH Plus, Roeko Seal, Ketac-Endo, Sultan	fluid filtration	2002
Wu et al.	240	AH26, Ketac-Endo, Sealapex, Tubliseal	fluid transport	1995
Haikel et al.	113	Sealapex, AH Plus, Topseal, Sealite	I-radiolabelled lysozyme	1999
Antonopoulos et al.	90	AH Plus	passive exposure to India ink negative pressure to India ink rhodamine B dye mixed with epoxy resin	1998
Canalda et al.	150	Endomethasone, Tubliseal, AH26, Diaket, Sealpex, CRS	radionuclide detection technique	1992

ing sealer. Miletic et al. [49] used the fluid transport model proposed by Wu et al. [50] and reported that after 1 year, AH Plus® (Dentsply, Konztanz, Germany) a sealer based on epoxy resin and Ketac-Endo shows significantly better sealing ability than Apexit, whereas AH26® and Diaket® (ESPE, Seefeld, Germany) both epoxy resin root canal sealers, show no statistical differences with either sealer.

However, very few studies dealing with the effect of different root canal sealers on apical dye penetration after obturation with Thermafil® Endodontic Obturator (Tulsa Dental, Tulsa, USA) [51] or System B® (Analytic Endodontics, Orange, USA) are available. Some materials like epoxy resin sealers are antimicrobially active only during the setting period, which is an interesting approach. For a short period, residual bacteria may be killed; in the long run, the material is non toxic, leaving time for the surrounding tissues to heal [52]. According to the manufacturer, AH Plus has excellent sealing properties without the drawback of the release of formaldehyde. The antibacterial effect of AH Plus may be related to bisphenol diglycidyl ether, which was previously identified as a mutagenic component of the resin-based material [53]. In an *in vitro* study, Almeida et al. [54] observed that leakage with AH Plus was significantly less than that with the ZnOE sealer (Fill Canal®) as well as with Ketac-Endo. Greater measured leakage for sealers based on ZnOE compared with epoxy resin-based sealers was also found by other authors [46, 55]. When the performance of different sealers was compared, it has often been shown that AH26 performed better than the other root canal sealers [56]. Those investigations of the mechanical and biological properties of different sealers reflect the clinical interest in these materials and the belief that the type of sealer used will influence the outcome of the endodontic treatment. These studies, however, have shown that the sealers permit some degree of microleakage and the extent of microleakage that can be tolerated while maintaining a successful therapy has still not been established.

Several techniques of obturating root canals with gutta-percha and root canal sealers have been described. The development of predictable 3D obturation began in 1967 when Dr. Herbert Schilder described how waves of condensation, the movement of thermosoftened gutta-percha and sealer through a well-prepared root canal space, could consistently fill root canal aberrations [57]. This technique requires a well-tapered and shaped canal along with a proper master gutta-percha cone. Hydraulic forces exerted during the compaction of the softened, warm gutta-percha and sealer move the filling material throughout the canal space and into accessory, lateral canals, fins and loops. In an attempt to overcome the deficiencies of the cold lateral compactation technique, several methods of providing heat have been developed lately to soften gutta-percha.

In 1978, Johnson [58] described a technique of coating a metal carrier with thermoplasticized gutta-percha to obturate the root canal system. This obturation technique became commercially available under the name of Thermafil. The heating of the obturator is carried out into a special oven with temperature and time control. The heated gutta-percha becomes thermoplasticised and the obturator is then inserted into the root canal to the working length. On insertion of the obturator, the tapered plastic carrier allows the practitioner to exert both lateral and vertical compaction forces on the heated gutta-percha. The shape of the repaired root canal is clearly of paramount importance. Nevertheless, it should be noted that less coronal enlargement is needed with the Thermafil technique than with other warm vertical gutta-percha compaction techniques such as vertical compaction or System B®, which require more elimination of coronal dentine structure to allow the prefitting of the pluggers. After the cleaning and shaping have been completed, a verifier corresponding in size to the last instrument used to the working length is used to gauge the canal. The verifier should slide easily, without any contact with the canal walls, and should fit passively in its last 1 mm, with soft friction at the working length. The corresponding Thermafil obturator is then used to achieve the obturation of the canal. This method relies on the adjustment of the obturator silicone stop at the working length to control penetration and avoid overextension of the plastic carrier into the periapical tissues.

The Thermafil obturator should be dipped in a sodium hypochlorite solution for at least one minute to ensure its decontamination. In the meantime, the canal is dried with paper points and the root canal sealer is prepared. The manufacturer recommends the use of the paste-paste epoxy resin-based root canal sealer (Topseal®, Dentsply-Maillefer; AH plus, Dentsply). Because of its relatively fluid consistency, this sealer should be used carefully and only in very small amounts. Thus, to avoid extrusion of excess sealer in the periapical tissues, only the coronal third of the canal is coated with a small amount of sealer using a paper point. The obturator is then placed into the oven, which allows homogenous heating of the gutta-percha at the exact temperature. Heating time varies from 15 to 45 seconds, depending on the obturator size, and is regulated automatically.

When the obturator is ready for use, it is pulled out from the oven and inserted directly into the canal using a low, firm and continuous apical movement. As it moves apically, the diameter of the tapered plastic carriers increase, thereby exerting more hydraulic lateral pressure (wedging effect) on the thermoplasticised gutta-percha and sealer. The obturator is stabilized using light finger pressure to limit shrinkage of the gutta-percha while cooling. At that point, an X-ray might be taken to ensure the placement of the Thermafil obturator at the correct working length. The coronal gutta-percha around the plastic carrier is compacted using hand pluggers. The shaft of the obturator is then cut off at the canal orifice using a Thermacut® bur.

The sealing ability of Thermafil system has been evaluated in several *in vitro* studies reaching variable conclusions [59–62]. The system seems to provide a comparable sealing ability to cold, warm or hybrid condensation of gutta-percha. Thermafil has been reported to be superior to lateral condensation with respect to the sealing of and adaptation to canal walls [63–65] and to the filling of lateral canals, as seen in Figure 1. It also exhibits more apical leakage while using passive dye penetration [66–69]. Haddix et al. [70] showed significantly less leakage values with lateral condensation than with Thermafil. Saunders and Saunders [71] reported the sealing ability of glass ionomer root canal sealer used in root canals obturated by lateral condensation or Thermafil. After seven days, there was significantly less leakage in the teeth obturated with Thermafil, but after 4 months, there was no significant difference in leakage between the groups.

Da Silva et al. [72] have shown that all Thermafil fillings produced overfilling with both sealer and gutta-percha. However, being *in vitro* observations in plastic canals, these results cannot be regarded as directly representative of the clinical situation. Moreover, resistance by the periapical tissues and tissue pressure in the *in vivo* situation may reduce the occurrence or the extent of overfilling, although the exact effect of these variables is difficult to determine. Abarca et al. [73] reported that dye leakage and apical extrusion between Thermafil and lateral condensation techniques were not statistically different.

A new instrument, System B® Heat Source, was introduced to simplify the down-pack of gutta-percha [74, 75]. System B has been described as "the continuous wave technique". Using a single master cone and a heat source, the root canal is obturated by the softened gutta-percha and sealer under pressure from the heated plugger [76]. The System B heat source can monitor the temperature at the tip of its heat carrier

Fig. 1. Thermosoftened gutta-percha and sealer consistently fills the root canal and penetrate into the lateral canals

Ryc. 1. Uplastyczniona termicznie gutaperka i uszczelniacz ściśle wypełniają kanał korzeniowy i penetrują do kanałów bocznych

Fig. 2. Transversal view of a section obtained from a uniradicular teeth with System B. No microleakage in visible

Ryc. 2. Przekrój poprzeczny jednokorzeniowego zęba leczonego Systemem B. Mikroprzeciek nie jest widoczny

devices and can, therefore, deliver a precise amount of heat for an indefinite time. When this electric heat carrier is designed to be a plugger as well, the gutta-percha can be simultaneously softened and condensed. These pluggers are easy to select for a given canal preparation because they match non-standardized gutta-percha cones in taper. It is also recommended that the pluggers are to be used 4 to 6 mm short of the working length [77]. Eventually, the heat is conducted to the tip of the master gutta-percha cone. The main criticism to this technique is that only a single, uncondensed cone is present in the apical region to seal the root canal apex. Pommel and Camps [78] showed that System B was as effective as vertical condensation and Thermafil. All those techniques provided an effective apical seal that decreased slightly with time. These results are consistent with those published by Yared et al. [79] showing a constant increase in microleakage with vertical condensation over time. Silver et al. [80] reported that System B produce root fillings consisting of > 90% gutta-percha, as is shown in Figure 2. In terms of core/sealer ratio, Gençoglu et al. [81] found Thermafil to have the highest total core content. Thermafil was significantly better than

System B and lateral condensation. However, another leakage study by Kytridou et al. [82], determined that Thermafil demonstrated more apical extrusion and leakage than the System B.

The warm gutta-percha techniques have much to commend and undoubtedly the resultant root filling appears to be homogeneous and, judging from the radiographs, seem to fill the root canal space appropriately. So far *in vitro* studies have reported variable conclusions without answering the main question. The major reasons for such disagreement are the variety of evaluative methodologies and assessment parameters. This seem to be the reason for the absence of evidence to how which one of these techniques, Termafil or System B, result in higher clinical success.

References

[1] Schilder H.: Filling root canals in three dimensions. Dent. Clin. North Am. 1974, 11, 723–744.

[2] Gutmann J. L., Witherspoon D. E.: Obturation of the cleaned and shaped root canal system. In: Pathways of the Pulp. Eds: Cohen S., Burns R.C. Mo, USA: Mosby, St. Louis 2002, 8th ed., 289–358.

[3] Schafer E., Priv-Doz Dr., Olthoff G.: Effect of Three Different Sealers on the Sealing Ability of Both Thermafil Obturators and Cold Laterally Compacted Gutta-Percha. J. Endod. 2002, 28, 638–642.

[4] Bhambhani S. M., Sprechman K.: Microleakage comparison of Thermafil versus vertical condensation using two different sealers. Oral Surg. Oral Med. Oral Pathol. 1994, 78, 105–108.

[5] Anthony L. P., Grossman L. I.: A brief history of root canal therapy in the United States. J. Am. Dent. Assoc. 1945, 32, 43–50.

[6] Grossman L.: Physical properties of root canal cements. J. Endod. 1976, 2, 166–175.

[7] Orstavik D.: Endodontic materials. Adv. Dent. Res. 1988, 2, 12–24.

[8] Tronstad L., Barnett F., Flax M.: Solubility and biocompatibility of calcium hydroxide-containing root canal sealers. Endod. Dent. Traumatol. 1988, 4, 152–159.

[9] Weiger R., Heuchert T., Hshn R., Löst C.: Adhesion of a glass ionomer cement to human radicular dentine. Endod. Dent. Traumatol. 1995, 11, 214–219.

[10] Strindberg L. Z.: The dependence of the results of pulp therapy on certain factors. Acta Odontol. Scand. 1956, 14, 1–175.

[11] Madison S., Wilcox L. R.: An evaluation of coronal microleakage in endodontically treated teeth. Part III. *In vivo* study. J. Endod. 1988, 14, 455–458.

[12] Saunders W. P., Saunders E. M.: Coronal leakage as a cause of failure in root-canal therapy: a review. Endod. Dent. Traumatol. 1994, 10, 105–108.

[13] Mannocci F., Innocenti M., Bertelli E., Ferrari M.: Dye leakage and SEM study of roots obturated with Thermafil and dentin bonding agent. Endod. Dent. Traumatol. 1999, 15, 60–64.

[14] Kennedy W. A., Walker W. A., Gough R. W.: Smear layer removal effects on apical leakage. J. Endod. 1986, 12, 21–27.

[15] DuLac K., Nielsen C., Tomazic T., Ferillo P., Hatton J.: Comparison of the obturation of lateral canals by six techniques. J. Endod. 1999, 25, 376–380.

[16] Limkangwalmongkol S., Abbott P., Sandler A.: Apical dye penetration with four root canal sealers and gutta-percha using longitudinal sectioning. J. Endod. 1992, 18, 535–539.

[17] Bernath M., Szabo J.: Tissue reaction initiated by different sealers. Int. Endod. J. 2003, 36, 256–261.

[18] Boussetta F., Bal S., Romeas A., Boivin G., Magloire H., Farge P.: *In vitro* evaluation of apical microleakage following canal filling with a coated carrier system compared with lateral and thermomechanical Gutta-Percha condensation techniques. Int. Endod. J. 2003, 36, 367–371.

[19] Cobankara F. K., Adanir N., Belli S., Pashley D. H.: A quantitative evaluation of apical leakage of four root-canal sealers. Int. Endod. J. 2002, 35, 979–984.

[20] Antonopoulos K., Attin T., Hellwing E.: Evaluation of the apical seal of root canal fillings with different methods. J. Endod. 1998, 24, 655–658.

[21] Antonopoulos K. G., Attin T., Hellwing E.: Evaluation of the apical seal of root canal fillings with different methods. J. Endod. 1998, 24, 655–658.

[22] Chailertvanitkul P., Saunders W. P., Mackenzie D.: An assessment of microbial coronal leakage in teeth root filled with gutta-percha and three different sealers. Int. Endod. J. 1996, 29, 387–392.

[23] Haïkel Y., Wittenmeyer W., Bateaman G., Bentaleb A., Allemann C.: A new method for the quantitative analysis of endodontic microleakage. J. Endod. 1999, 25, 172–177.

[24] Larder T. C., Prescott A. J., Brayton S. M.: Gutta-percha: a comparative study of three methods of obturation. J. Endod. 1976, 2, 289–294.

[25] Robertson D., Leeb I. J., McKee M., Brewer E.: The clearing technique for the study of root-canal systems. J. Endod. 1980, 6, 421–424.

[26] Czanstkowsky M., Michanowicz A., Vazques J. A.: Evaluation of an injection of thermoplasticized low temperature gutta-percha using radioactive isotopes. J. Endod. 1985,11, 71–74.

[27] Jacquot B., Panighi M., Steinmetz P., G'Sell C.: Evaluation of temporary restorations by means of electrochemical impedance measurements. J. Endod. 1996, 22, 586–589.

[28] Kersten H. W., Ten Cate J. M., Exterkate R. A., Moorer W. R., Thoden van Velzen S. K.: A standardized leakage test with curved root canals in artificial dentine. Int. Endod. J. 1988, 21, 191–199.

[29] Al-Ghamdi A., Wennberg A.: Testing of sealing ability of endodontic filling materials. Endod. Dent. Traumatol. 1994, 10, 249–255.
[30] Wu M. K., Wesselink P. R.: Endodontic leakage studies reconsidered. Part I. Methodology, application and relevance. Int. Endod. J. 1993, 26, 37–43.
[31] Canalda-Sahli C., Brau-Aguade E., Sentis-Vilalta J., Aguade-Bruix S.: The apical seal of root canal sealing cements using a radionuclide detection technique. Int. Endod. J. 1992, 25, 250–256.
[32] Scuurs A. H., Wu M. K., Wesselink P. R., Duivenvoorden H. J.: Endodontic leakage studies reconsidered. Part II. Statistical aspects. Int. Endod. J. 1993, 26, 44–52.
[33] Pommel L., Camps J.: Effect of pressure and measurement time on the fluid filtration method in endodontics. J. Endod. 2001, 27, 256–258.
[34] Derkson G. D., Pashley D. H., Derkson M. E.: Microleakage measurement of selected restorative materials: a new *in vitro* method. J. Prosthet. Dent. 1986, 56, 435–440.
[35] Pashley E. L., Tao L., Pashley D. H.: The sealing properties of temporary filling materials. J. Prosthet. Dent. 1988, 60, 292–297.
[36] Goldberg F., Massone E. J., Artaza L. P.: Comparison of the sealing capacity of three endodontic filling techniques. J. Endod. 1995, 21, 1–3.
[37] Ramachandran N.: Apical periodontitis: a dynamic encounter between root canal infection and host response. Periodontology 2000, 1997, 13, 121–148.
[38] Pommel L., Jacquot B., Camps J.: Lack of correlation among three methods for evaluation of apical leakage. J. Endod. 2001, 27, 347–350.
[39] Roig M., Ribot J., Jane L., Canalda C.: Estudio de la filtracion apical de cuatro cementos de obturacion. Endodoncia 1996, 14, 21–27.
[40] Naidorf I. J.: Clinical microbiology in endodontics. Dent. Clin. North Am. 1974, 18, 329–344.
[41] Saunders W. P., Saunders E. M.: The effect of smear layer upon the coronal leakage of gutta-percha root filling and a glass ionomer sealer. Int. Endod. J. 1992, 25, 245–249.
[42] Yoshida M., Fukushima H., Yamamoto K., Ogawa K., Toda T., Sagawa H.: Correlation between clinical symptoms and microorganisms isolated from root canals of teeth with periapical pathosis. J. Endod. 1987, 13, 24–28.
[43] Nair P. N. R., Sjogren U., Krey G., Kahnberg K. E., Sundiqvist G.: Intraradicular bacteria and fungi in root-filled asymptomatic human teeth with therapy-resistant periapical lesions: a long-term light and electron microscopic follow-up study. J. Endod. 1990, 12, 580–588.
[44] Kazemi R. B., Safavi K. E., Spangberg L. S.: Dimensional changes of endodontic sealers. Oral Surg. Oral Med. Oral Pathol. 1993, 76, 766–771.
[45] Smith M. A., Steiman H. R.: An *in vitro* evaluation of microleakage of two new and two old root canal sealers. J. Endod. 1994, 20, 18–21.
[46] Oguntebi B. R., Shen C.: Effect of different sealers on thermoplasticized gutta-percha root canal obturations. J. Endod. 1992, 18, 363–366.
[47] Lim K. C., Tidmarsh B. G.: The sealing ability of Sealapex compared with AH26. J. Endod. 1986, 12, 564–566.
[48] Özara F., Önal B., Erdilek N., Türkün S.: A comparative study of apical leakage af Apexit, Ketac-Endo, and Diaket root canal sealers. J. Endod. 1999, 25, 603–604.
[49] Miletic I., Ribaric S., Karlovic Z., Jukic S., Bosnjak A., Anic I.: Apical leakage of five root canal sealers after one year of storage. J. Endod. 2002, 28, 431–432.
[50] Wu M. K., De Gee A. J., Wesselink P. R., Moorer W. R.: Fluid transport and bacterial penetration along root canal fillings. Int. Endod. J. 1993, 28, 185–189.
[51] Bhambhani S. M., Sprechman K.: Microleakage comparison of Thermafil versus vertical condensation using two different sealers. Oral Surg. Oral Med. Oral Pathol. 1994, 78, 105–108.
[52] Bergenholtz G., Horsted-Bindslev P., Reit C.: Textbook of Endodontology. Blackwell, Munksgaard 2003.
[53] Heil J., Reifferscheid G., Waldmann P., Leyhausen G., Geurtsen W.: Genotoxicity of dental materials. Mutat. Res. 1996, 368, 181–194.
[54] De Almeida W. A., Leonardo M. R., Tanomaru F. M., Silva L. A. B.: Evaluation of apical sealing of three endodontic sealers. Int. Endod. J. 2000, 33, 25–27.
[55] Limkangwalmongkol S., Burtscher P., Abbott P. V., Sandler A. B., Bishop B. M.: A comparative study of the apical leakage of four root-canal sealers and laterally condensed gutta-percha. J. Endod. 1991, 7, 495–499.
[56] Wu M. K., Wesselink P. R., Boersma J.: A 1-year follow-up study on leakage of four root canal sealers at different thicknesses. Int. Endod. J. 1995, 28, 185–189.
[57] Schilder H.: Filling root canals in three dimensions. Dent. Clin. North Am. 1967, 11, 723–744.
[58] Johnson W. B.: A new gutta-percha technique. J. Endod. 1978, 4, 184–188.
[59] Bhambhani S. M., Sprechman K.: Microleakage comparison of Thermafil versus vertical condensation using two different sealers. Oral Surg. Oral Med. Oral Pathol. 1994, 78, 105–108.
[60] Dalat D. M., Spangberg L. S.: Comparison of apical leakage in root canals obturated with various gutta-percha techniques using a dye vacuum tracing method. J. Endod. 1994, 20, 315–319.
[61] Cohen B. I., Pagnillo M. K., Musikant B. L., Deutsch A. S.: The evaluation of apical leakage for three endodontic fill systems. General Dent. 1999, 46, 618–623.
[62] Lares C., El Deeb M. E.: The sealing ability of Thermafil obturation technique J. Endod. 1990, 16, 474–479.
[63] Gençoglu N., Samani S., Günday M.: Evaluation of sealing properties of Thermafil and Ultrafil techniques in absence or presence of smear layer. J. Endod. 1993, 19, 599–603.

[64] Beatty R. G., Baker P. S., Haddix, Hart F.: The efficacy of four root canal obturation techniques in preventing apical dye penetration. JADA 1989, 119, 633–637.
[65] Gilbert S. D., Witherspoon D. E., Berry C. W.: Coronal leakage following three obturation techniques. Int. Endod. J. 2001, 33, 415–420.
[66] Gulabivala K., Holt R., Long B.: An *in vitro* comparison of thermoplasticized gutta-percha obturation techniques with cold lateral condensation. Endod. Dent. Traumatol. 1998,14, 262–269.
[67] McMurtrey L. G., Krell K. V., Wilcox L. R.: A comparison between Thermafil and lateral condensation in highly curved canals. J. Endod. 1992, 18, 68–71.
[68] Dummer P. M., Kelly T., Meghji A., Sheikh I., Vanitchai J. T.: An *in vitro* study of the quality of root fillings in teeth obturated by lateral condensation of gutta-percha or Thermafil obturators. Int. Endod. J. 1993, 26, 99–105.
[69] Baumgardner K., Taylor J., Walton R.: Canal adaptation and coronal leakage: lateral condensation compared to Thermafil. JADA 1995, 126, 351–356.
[70] Haddix J. E., Jarrel M., Mattison G. D., Pink F. E.: An *in vitro* investigation of the apical seal produced by a new thermoplasticized gutta-percha obturation technique. Quintes. Int. 1991, 22, 159–163.
[71] Saunders W. P., Saunders M. E.: Influence of smear layer on the coronal leakage of Thermafil and laterally condensed gutta-percha root fillings with a glass ionomer sealer. J. Endod. 1994, 20, 155–158.
[72] Da Silva D., Endal U., Reynaud A., Portenier I., Ørstavik D., Haapasalo M.: A comparative study of lateral condensation, heat-softened gutta-percha, and a modified master cone heat-softened backfilling technique. Int. Endod. J. 2002, 35, 1005–1011.
[73] Abarca A. M., Bustos A., Navia M.: A comparison of apical sealing and extrusion between Thermafil and lateral condensation techniques. J. Endod. 2001, 27, 670–672.
[74] Buchanan L. S.: The continuous wave of condensation technique: a convergence of conceptual and procedural advances in obturation. Dent. Today 1994, 13, 80–85.
[75] Buchanan L. S.: The continuous wave of obturation technique: centered condensation of warm gutta-percha in 12 seconds. Dent. Today 1996,15, 60–67.
[76] Buchanan L. S.: Continuous wave of condensation technique. Endod. Prac. 1998, 1, 7–10, 13–16, 18.
[77] Buchanan S.: The continuous wave of condensation technique: a convergence of conceptual and procedural advances in obturation. Dent. Today 1994, 13, 80–85.
[78] Pommel L., Camps J.: *In vitro* apical leakage of System B compared with other filling techniques. J. Endod. 2001, 27, 449–451.
[79] Yared G., Bou Dadher F. E.: Influence of plugger penetration on the sealing ability of vertical condensation. J. Endod. 1995, 21, 152–153.
[80] Silver G. K., Love R. M., Purton D. G.: Comparison of two vertical condensation obturation techniques. Int. Endod. J. 1999, 32, 287–295.
[81] Gençoglu N., Garip Y., Bas M., Samani S.: Comparison of different gutta-percha root filling techniques: Thermafil, Quick-Fill, System B, and lateral condensation. Oral Surg. Oral Med. Oral Pathol. 2002, 93, 333–336.
[82] Kytridou V., Gutmann J. L., Nunn M. H.: Adaptation and sealability of two contemporary obturation techniques in the absence of the dentinal smear layer. Int. Endod. J. 1999, 32, 464–474.

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