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Coronal leakage of calcium phosphate-based root canal sealers compared with usual sealers

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Summary

The purpose of the present study was to compare two experimental calcium phosphate-based sealers with AH Plus, Sealapex, Ketac-Endo and Hermetic with regard to coronal seal. Two standardized artificial canals were prepared in each of 120 blocks of bovine root dentin. The blocks were divided into six groups. All of the 40 canals of each group were filled with gutta-percha and either AH Plus, Hermetic, Ketac-Endo, Sealapex or two different experimental sealers. One canal of one block was filled with gutta-percha and sealer using lateral condensation, whilst the other canal was obturated using Thermafil. The roots were immersed in black ink and thereafter cleared. Maximum linear dye penetration was measured coronally. Statistical analysis was performed by means of the Kruskal-Wallis test for the global null hypothesis and the closed test procedure for pairwise comparisons. With lateral condensation, experimental sealer I was comparable with AH Plus and Hermetic but showed significantly higher penetration depths than Ketac-Endo and Sealapex. Using Thermafil, more leakage was found for experimental sealer I than for AH Plus, Ketac-Endo and Sealapex. Using both techniques, leakage of experimental sealer II did not differ significantly from leakage of AH Plus, Ketac-Endo and Sealapex. Due to the low leakage of experimental sealer II in the present study, further evaluations such as bacterial penetration or fluid filtration should follow.

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Introduction

Coronal leakage following root canal treatment can impact unsuccessful outcomes (SRITHARAN 2002, WU & WESSELINK 1993). Microorganisms and nutrients may enter coronally via a permeable or leaking coronal restoration, or via dentinal tubules of a root denuded of cementum. Then leaking root canal fillings may enable further bacterial penetration which may be responsible for periapical inflammation.

Endodontic sealers are frequently placed in direct contact with living tissues. Therefore, they should have a good biocompatibility. Calcium phosphate cements are supposed to be suitable for sealing root canals. HONG et al. (1991) found an excellent biocompatibility by intentionally pressing the calcium phosphate sealer into the periapical tissue of monkeys. Several in vivo studies with similar results followed (BILGINER et al. 1997, SUGAWARA et al. 1992, YOSHIKAWA et al. 1997, YUAN et al. 2000). To date, there are no studies investigating coronal leakage and only a few studies investigating apical sealing ability of calcium phosphate-based sealers that show comparable outcome as Sealapex or zinc oxide-eugenol-based sealers (BILGINER et al. 1997, CHERNG et al. 2001, YOSHIKAWA et al. 1996). Information about the coronal sealing ability is needed. Therefore, the aim of this study was to compare two experimental calcium phosphate-based sealers with AH Plus, Sealapex, Ketac-Endo and Hermetic regarding coronal dye penetration using a new study design with standardized canals.

Materials and Methods

120 extracted single rooted bovine mandibular anterior teeth were used. After extraction, all teeth were cleaned of gross debris with scalpels, and stored in 0.5% Thymol. The crowns were separated from the roots at the cemento-dentinal junction using a diamond-coated band saw (Exakt, Norderstedt, Germany) under continuous water cooling, and the pulps were removed thoroughly with K-files. Parallel to the first cut, the apical region was removed using the band saw. Thus, 15 mm blocks of bovine dentin emerged.
The roots were clamped in a vice. In each root, two 14 mm deep canals with a 0.7 mm diameter were drilled between the root surface and the pulp chamber from the coronal site using a HSS-spiral drill (Albrecht, Freiburg, Germany) under continuous water cooling (Fig. 1). To achieve a taper between 2% and 4%, all canals were flared with K-files size ISO #60 and ISO #70 (Vereinigte Dentalwerke, München, Germany) in a circumferential filing motion. NaOCl (1%) was used as irrigation solution after each file. At the apical end of each canal, an "apical foramen" with a 0.3 (± 0.025) mm diameter was created using a diamond bur (Fig. 1). Subsequently, the canals were dried with paper points. Then the roots were randomly divided into six groups of 20 and filled with gutta-percha and one of the following sealers (Table I): Group 1: AH Plus (Dentsply, Konstanz, Germany), Group 2: Hermetic (Lege artis, Dettenhausen, Germany), Group 3: Ketac-Endo (3M Espe, Seefeld, Germany), Group 4: Sealapex (Kerr, Karlsruhe, Germany), Group 5: experimental sealer I (Augmentech, Wetzlar, Germany), Group 6: experimental sealer II (Augmentech).
The two artificial canals of each root were filled using different obturation techniques. One canal was filled using lateral condensation, whilst the second one was obturated using the Thermafil system (Dentsply, Konstanz, Germany).
The sealers were mixed according to the manufacturers' instructions. Experimental sealer I was mixed to a creamy consistency. Experimental sealer II was mixed using a capsule system. The compositions of the calcium phosphate-based root canal sealers are given in Table I. Percentages are manufacturer's secret.
It was not possible to blind the operator because of the different appearance of the types of sealers.

Lateral condensation

A standard size (ISO #70) gutta-percha cone (Vereinigte Dentalwerke) was marked at the working length and tug-back was determined. The gutta-percha cone was coated with sealer and seated gently to the working length. Cold lateral condensation was performed using finger-spreaders (size 15, Vereinigte Dentalwerke), and accessory cones (size 15, Vereinigte Dentalwerke) were used. In this manner, four accessory cones were inserted

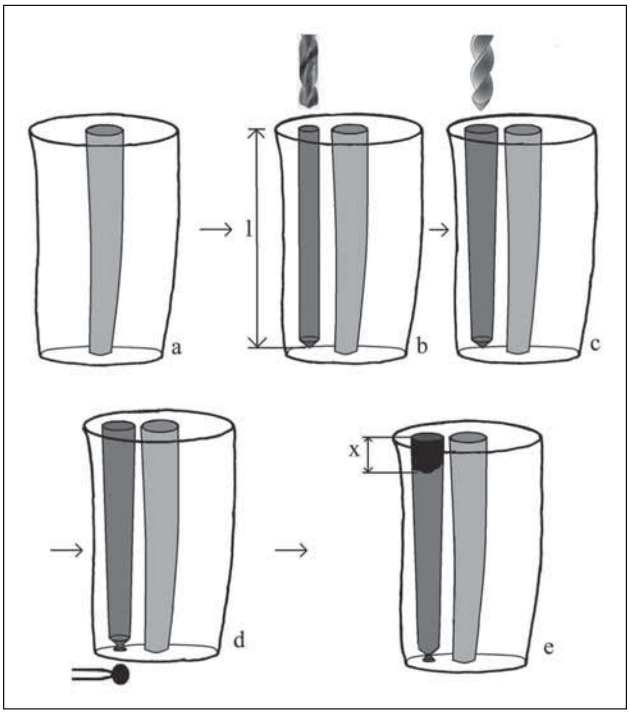

Fig. 1 Experimental setup: illustration of the preparation of an artificial root canal. a) block of bovine dentine (length of 15 mm), b) drilling of a canal (l = 14 mm, diameter = 0.7 mm), c) flaring with K-files size ISO #60 and ISO #70, d) preparation of an apical foramen using a diamond bur, e) situation after root canal obturation, dye penetration (x) and clearing

Tab. I Composition of the sealers

Sealer	Component A	Component B
AH Plus (Dentsply, Konstanz, Germany)	– epoxy resins – calcium tungstate – zirconium oxide – silica – iron oxide pigments	– amines – calcium tungstate – zirconium oxide – silica – silicone oil
Hermetic (Lege artis, Dettenhausen, Germany)	– zinc oxide – zirconium oxide – zinc acetate	– eugenol – peruvian balsam
Ketac-Endo (3M Espe, Seefeld, Germany)	– calcium-lanthanum-sodium – fluorophosphate-aluminium-silicate	– poly acrylic acid – tartaric acid
Sealapex (Kerr, Karlsruhe, Germany)	– calcium hydroxide – zinc oxide	– polymethylene salicylate resin – barium sulfate – titanium dioxide
experimental sealer I (Augmentech, Wetzlar, Germany)	– dicalcium sodium potassium diphosphate – calcium potassium phosphate – monocalcium phosphate monohydrate	– distilled water (1 g powder: 1 ml liquid)
experimental sealer II (Augmentech, Wetzlar, Germany)	– α-tricalcium phosphate – magnesium phosphate – magnesium hydrogen phosphate – strontium carbonate	– 3.5-molar solution of diammonium hydrogen phosphate (1 g powder: 0.8 ml liquid)

in a standardized way. The first accessory cone was inserted 1 to 2 mm short of working length. Excess gutta-percha was removed from the coronal portion of the root canal using a heated instrument, and the material was condensed vertically using a plugger.

Thermafil system

A standardized size of Thermafil obturator was selected using the Thermafil size verification kit. The coronal third of the artificial canal was lightly coated with sealer using paper points. The canal was obturated according to the manufacturer's recommendation. Each Thermafil obturator was heated in the Therma-Prep Oven and inserted to the working length. The handle of the obturator was cut at the canal orifice using a high-speed bur. The gutta-percha, still in the thermoplasticized phase, was condensed vertically around the carrier with a hand plugger.

The samples were stored at 37 °C in 100% humidity for seven days to ensure complete setting of the sealers. Then the coronal parts of the roots were immersed in black ink (Schwarze Kunstschrifttusche, Pelikan, Hannover, Germany) for seven days using passive dye penetration. After immersion, the specimens were rinsed under running tap water to remove the ink from the external surfaces. The specimens were demineralized in 5% nitric acid for 72 h, washed for 4 h and dehydrated in increasing concentrations of alcohol (80% for 12 h, 90% for 1 h, and 99% for 3 h). Subsequently, the roots were cleared using methyl salicylate (Merck, Darmstadt, Germany).

For determination of dye penetration, each cleared root was rotated until measuring of maximum penetration depth of each root canal filling was possible (Fig. 1). This view was photographed using a CCD-sensor (Sony, Tokyo, Japan) that was connected with a light microscope (×6.5; Leica Wild M3Z, Wetzlar, Germany). The software "Square Root 2.0" (Brücklmeier, Berlin, Germany) was used to determine the maximum linear penetration depth.

Statistical analysis was performed by means of the Kruskal-Wallis test for the global null hypothesis and the closed test procedure for pairwise comparisons. All statistics were performed using SAS 6.12 (SAS Institute Inc., Cary, North Carolina, USA). Level of significance was set at $p < 0.05$.

Results

Mean dye penetration, standard deviations, medians and statistically significant differences ($p < 0.05$) are shown in Table II. Ketac-Endo group showed the lowest mean of penetration depths when used with both obturation techniques.

Using lateral condensation, canals sealed with experimental sealer I leaked significantly more than canals sealed with experimental sealer II, Ketac-Endo and Sealapex. The sealing ability of experimental sealer II did not differ significantly from that of AH Plus, Ketac-Endo and Sealapex, but in experimental sealer II group less penetration depth was observed than in the Hermetic group.

No significant difference was observed between leakage of experimental sealer II and the other sealers when using Thermafil. Significantly higher penetration depths were found for experimental sealer I compared to AH Plus, Ketac-Endo and Sealapex.

Discussion

Extracted human teeth were used in most of the leakage studies available in the literature. Because of the different anatomy of natural root canals, a large variation of results could be expected. Wu & Wesselink (1993) regarded this fact as a major reason for the differing results between the various investigations of sealing ability. Therefore, other models using dentin as a substrate seem preferable.

In the present study, standardized artificial canals were prepared in bovine root dentin. The chemical constitution (percentages of calcium, phosphorus and magnesium) of bovine dentin is very similar to the chemical constitution of human dentin. Also concerning density and thermal capacity bovine dentin corresponds with human dentin (Esser et al. 1998). Number and density of dentinal tubuli of human dentin are higher compared with bovine dentin. Furthermore, the density of dentinal tubuli of bovine root dentin near the pulp is higher than in the central dentinal area (Esser et al. 1998). Because of a minor dentin thickness of human teeth, preparation of artificial canals in human dentin seemed impossible. When regarding the main advantage of the new design, it becomes clear that failures in preparation of the canal and the different anatomy would not impact on the outcome of the study.

In recent years, microbiological studies have been performed for determination of leakage. However, measurement of maximum apical or coronal linear dye penetration has been widely used because it is a simple technique to evaluate the sealing ability of an obturated root canal, in particular with regard to newly developed materials or techniques which should be preclinically tested in an in vitro setup (Abarca et al. 2001, Britto et al. 2002, De Moor & De Bruyne 2004, Kataoka et al. 2000, Oliver & Abbott 1998, Schäfer & Olthoff 2002, Vizgirda et al. 2004).

It must be emphasized that extrapolation to the clinical performance and bacterial leakage is not possible. In some former studies, vacuum conditions were used for dye penetration in order to reduce air bubbles. Regarding coronal leakage, no significant difference was found between the fluid filtration method

Tab. II Extent of coronal dye penetration (mm)

Obturation technique		**Lateral condensation**				**Thermafil system**			
Group	**n**	**Mean**	**SD**	**Median**	**Signif**	**Mean**	**SD**	**Median**	**Signif**
AH Plus	20	0.40	0.42	0.38	B, C	0.50	0.70	0.00	A, B
Hermetic	20	1.15	1.57	0.57	D	0.84	1.20	0.41	B, C
Ketac-E.	20	0.14	0.18	0.00	A	0.24	0.48	0.00	A
Sealapex	20	0.18	0.18	0.13	A, B	0.25	0.43	0.00	A, B
Exp I	20	0.73	0.71	0.69	C, D	1.66	1.46	1.61	C
Exp II	20	0.35	0.53	0.00	A, B	1.12	1.53	0.00	A, B, C

Exp indicates experimental sealer, Signif indicates significant differences: for each obturation technique, sealers with the same characters showed not significantly different penetration depths at $p < 0.05$.

and passive dye penetration. Studies using vacuum resulted in higher penetration depths than fluid filtration and passive dye penetration (WIMONCHIT et al. 2002). However, several studies regarding apical dye leakage have indicated that filling materials or obturation techniques did not differ significantly when considering evaluation techniques using vacuum (DICKSON & PETERS 1993, MASTERS et al. 1995, RODA & GUTMANN 1995). Thus, the present study was carried out without the use of vacuum.

For measurement of penetration depths, roots were rendered transparent in the present study because this allowed evaluating the artificial canals three-dimensionally. Thus, the maximum depth of dye penetration could be accurately recorded in each direction.

In the literature, there are only a few dye penetration studies comparing root canal sealers referring to coronal leakage. Using lateral condensation, no difference was found between Sealapex and the zinc oxide-eugenol-based Pulp Canal Sealer EWT (Kerr/Sybron, Romulus, MI, USA) regarding coronal leakage (KATAOKA et al. 2000). The sealing ability of AH Plus was found comparable to that of AH 26 after using lateral condensation (DE MOOR & DE BRUYNE 2004), and leakage after use of AH 26 did not differ significantly from Ketac-Endo (OLIVER & ABBOTT 1998). A 3D reconstruction of dye microleakage showed more coronal leakage with the zinc oxide-eugenol-based Roth's 801 (Roth Dental Company, Chicago, IL, USA) than with Ketac-Endo (LYROUDIA et al. 2000). This is in accordance with the results of the present study which shows more leakage with the zinc oxide-eugenol-based sealer Hermetic than with Ketac-Endo. In a study using the Thermafil system, AH Plus revealed penetration depths comparable with AH 26 (DE MOOR & DE BRUYNE 2004).

Some studies regarding apical leakage found that calcium phosphate-based sealers were comparable to usual sealers like Sealapex or zinc oxide-eugenol-based sealers (BILGINER et al. 1997, CHERNG et al. 2001, YOSHIKAWA et al. 1996). In the present study regarding coronal leakage, in particular the experimental sealer II performed as well as AH Plus, Hermetic, Ketac-Endo and Sealapex, or even better.

The reason for the better seal of experimental sealer II in comparison to experimental sealer I might be the mixture in the capsule that leads to an accurate powder-liquid ratio and an improved mixture. Furthermore, the gutta-percha cones seemed to be better wettable with experimental sealer II than with experimental sealer I, where the cones seemed to be repellent. When using the Thermafil system, the difference between experimental sealer I and II was not significant.

The relationship between dye penetration and the success of root canal treatment is not clear. Many factors, such as the kind of dye, the immersion time, the presence or absence of a smear layer, whether or not a vacuum or thermal cycling were used, make comparisons among studies difficult. Nevertheless, leakage between the filling material and the root canal wall would allow coronal ingress of microorganisms and nutrients. Thus, the development and maintenance of a leak-proof seal is considered to be a major prerequisite for success of any root canal treatment. Dye leakage tests may be helpful to find new materials allowing hermetic seal between root canal filling and dentin, even if the degree to which laboratory studies are clinically relevant should always be carefully considered.

Conclusions

The new study design seems very suitable for comparing root canal filling materials and obturation techniques, and should be followed by bacterial penetration or fluid filtration studies. The low leakage of the calcium phosphate-based sealer II found under the conditions of the present study support the assumption that it could perform very well as root canal sealers. Because of the proven sealing ability of the experimental sealers in this dye leakage study further research with regard to bacterial penetration or fluid filtration and clinical studies should follow.

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Zusammenfassung

Das Ziel der vorliegenden Untersuchung war der Vergleich der koronalen Dichtigkeit von zwei experimentellen Kalziumphosphat-Sealern und AH Plus, Sealapex, Ketac-Endo und Hermetic. In 120 bovinen Wurzeldentinblöcken wurden je zwei standardisierte künstliche Kanäle präpariert. Die Blöcke wurden in sechs Gruppen aufgeteilt. 40 Kanäle jeder Gruppe wurden mit Guttapercha und entweder AH Plus, Hermetic, Ketac-Endo, Sealapex oder einem der beiden experimentellen Sealer gefüllt. Ein Kanal eines Blocks wurde mittels lateraler Kondensationstechnik, der zweite mit Thermafil gefüllt. Die Wurzeln wurden in schwarzer Tusche gelagert und anschliessend transparent gemacht. Die maximale koronale Farbstoffpenetrationstiefe wurde linear gemessen. Die statistische Analyse erfolgte mit Hilfe des Kruskal-Wallis-Tests und der Abschlusstestprozedur für paarweise Vergleiche. Der experimentelle Sealer I war in Kombination mit der lateralen Kondensationstechnik vergleichbar mit AH Plus und Hermetic, zeigte aber signifikant geringere Penetrationstiefen als Ketac-Endo und Sealapex. Bei den mit Thermafil gefüllten Kanälen wurde mehr Undichtigkeit bei dem experimentellen Sealer I beobachtet als bei AH Plus, Ketac-Endo und Sealapex. Bei beiden Techniken waren zwischen dem experimentellen Sealer II und AH Plus, Ketac-Endo und Sealapex keine signifikanten Unterschiede festzustellen. Aufgrund der guten Dichtigkeit des experimentellen Sealers II in der vorliegenden Studie sollten weitere Untersuchungen wie beispielsweise Bakterienpenetrationsversuche folgen.

Résumé

Le but de cette étude était de comparer l'étanchéité coronaire de deux sealers à base de phosphate de calcium avec AH Plus, Sealapex, Ketac-Endo et Hermetic. Deux canaux artificiels standardisés ont été préparés dans chacun des 120 blocs de racines dentaires de bovins. Les blocs ont été divisés en six groupes. Quarante canaux de chaque groupe ont été obturés avec du gutta-percha et soit avec AH Plus, Hermetic, Ketac-Endo, Sealapex, soit avec l'un des deux sealers expérimentaux. Le premier des deux canaux d'un bloc a été obturé au moyen d'une technique manuelle conventionnelle, tandis que le second canal l'a été avec Thermafil. Les racines ont été conservées dans de l'encre de Chine, puis rendues transparentes. La profondeur de pénétration maximale du colorant fut mesurée linéairement. Les résultats ont été analysés statistiquement au moyen du test de Kruskal-Wallis. En combinaison avec la technique manuelle conventionnelle, le sealer expérimental I était comparable à AH Plus et Hermetic, mais montrait de façon significative une profondeur de pénétration moindre que Ketac-Endo et Sealapex. Dans le cas des canaux obturés avec Thermafil, plus de défauts d'étanchéité ont été

observés avec le sealer expérimental I qu'avec AH Plus, Ketac-Endo et Sealapex. Il n'y a pas eu de différence significative entre le sealer expérimental II et AH Plus, Ketac-Endo et Sealapex pour les deux techniques d'obturation. Sur la base de la bonne étanchéité du sealer expérimental II, démontrée dans le cadre de ce travail, les études devraient être poursuivies, par exemple dans le domaine de la pénétration bactérielle.

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