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Original Research

Evaluation of the physicochemical properties of intracanal medications used in traumatized teeth

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Aim: The aim of the present study was to evaluate the solubility, flow and radiopacity of Calen (SS White Artigos Dentários Ltd, Rio de Janeiro, Brazil), Calen with zinc oxide (Calen/ZnO), calcium hydroxide + zinc oxide + 2% chlorhexidine (CH/ZnO/CHX), Calplus and Ultracal XS. **Methods:** 28 bovine incisor specimens were standardized, instrumented and filled with pastes with the aid of a centrix syringe. To assess solubility, the root canals of acrylic teeth (N = 10) were filled with the previously mentioned pastes and scanned by using micro–computed tomography before (initial) and after 7 days of immersion in ultrapure water. The solubility of each specimen was the difference between the initial and final volume. Flow properties were analysed according to the ISO 6876/2012 standard. Radiopacity was radiographically analysed by using Image J software. Data were submitted to analysis of variance and Tukey's test (alpha 5%). **Results:** CH/ZnO/CHX and Calplus presented similar values regarding radiopacity. The group composed of Calen paste showed higher flow values. As for solubility, CH/ZnO/CHX showed lower volume loss, but there was no statistical difference compared to other medications. **Conclusion:** The medication composed of calcium hydroxide, zinc oxide and 2% chlorhexidine is a suitable alternative for use in traumatized teeth.

Keywords: Endodontics. Calcium hydroxide. Physical phenomena.

Introduction

Therapeutic measures for teeth with a history of dental trauma vary according to type of trauma, pulp and periapical condition, and stage of root formation. The main sequelae resulting from dental trauma are pulp necrosis and bacterial infection[1]. However, depending on the stage of tooth formation, there is a need to use techniques that induce the formation of an apical barrier for apical closure.

Apexification is a technique that can be performed in two ways: the first by using an apical barrier of a calcium silicate-based cement, such as mineral trioxide aggregate (MTA)[2,3], and subsequent conventional obturation; or by successively changing medications aiming to eliminate or at least to reduce the number of microorganisms, increase pH, induce dentin formation and repair periapical tissues[4,5].

Calcium hydroxide has been widely used as a medication with different vehicles in endodontics[6]. Its association with 2% chlorhexidine (CHX) results in an increased action against Gram-positive and Gram-negative bacteria[7,8]. The vehicle mixed with CHX determines the ionic dissociation rate, solubility and diffusibility[9]. Nevertheless, some vehicles provide faster dissociation, thus promoting faster alkalinity of dentin and apical and periapical tissues[10]. As the materials used in the root canal need to seal the apical portion of the root, they must have low solubility in order to prevent the release of irritating substances into the periapical tissues without allowing bacterial infiltration over time[11,12].

The use of an intracanal medication as a paste composed of calcium hydroxide, zinc oxide and 2% chlorhexidine gel (CH/ZnO/CHX) in a 2:1:2 ratio was proposed by de Jesus Soares et al.[13,14] in cases of trauma to teeth with complete or incomplete root formation and pulp necrosis without the need for periodic replacements until formation of apical barrier. The use of 2% chlorhexidine gel as a vehicle increases the antibacterial action[15-17] and does not change the pH of calcium hydroxide[15]. Zinc oxide is used to increase the consistency of the paste and to promote radiopacity, thus facilitating radiographic confirmation of filling[4]. Biocompatibility was also evaluated, showing favorable outcomes[18], decrease in signs and symptoms, and stabilization of root resorption[14,19-21].

As CH/ZnO/CHX-based medication requires no successive changes, as is the case of calcium hydroxide, and remains for longer periods of time[14] within from the root canal of traumatized teeth, its physicochemical properties (e.g. solubility and dimensional changes), flow capacity and radiopacity need to be evaluated because they play a fundamental role in the repair of the tooth according to normal biological standards.

As for dimensional changes, it is essential to obtain a linear stability not exceeding 1% or 0.1% in expansion[22] in order to avoid compromising the root canal filling and recontamination[12]. The greater the flow, the better the capacity of the material to penetrate into the dentinal tubules, including lateral and accessory root canals[23], thus reducing re-infection of the root canal system. Radiopacity is an important property of filling materials as it allows observing the entire extension and condensation of the material within the root canal[24].

Considering the aforementioned, this study aimed to evaluate the solubility, flow and radiopacity of intracanal medications commonly used in the treatment of traumatized teeth and to compare them with a medication composed of calcium hydroxide, 2% chlorhexidine gel, and zinc oxide (2:1:2), which presents no need for periodic changes.

Material and Methods

Experimental Groups

This is an *in vitro* study which evaluated the physical properties of the following experimental groups:

- Calen®
- Calen/ZnO - Calen® associated with zinc oxide in a 2:2 ratio
- CH/ZnO/CHX - paste of calcium hydroxide, 2% chlorhexidine gel, and zinc oxide
- Calplus - Calplus® toothpaste
- Ultracal XS - UltraCal® XS toothpaste

Assessment of Solubility and Dimensional Change

For specimen preparation, 28 recently extracted intact bovine incisors were used. The coronal portion was removed with the aid of a double-sided diamond disc (KG Sorensen, Barueri, SP, Brazil), thus standardizing the roots at a length of 14 mm. To standardize the internal root canals, they were instrumented with a #4 size drill under abundant irrigation with saline solution and 2% chlorhexidine gel, which was used as an auxiliary chemical substance. All experimental groups (n=7) had their teeth filled by using Centrix injection (DFL, Indústria e Comércio S.A, Rio de Janeiro, RJ, Brazil.). The cervical portion of the root was sealed with 1 mm of Coltosol (Vigodent S/A Indúsria e Comércio, Rio de Janeiro, RJ, Brazil) and then with light-cured resin (Filtek Z350, 3M Dental Products, Saint Paul, MN, United States of America).

Dimensional Change Assessment

Next, the specimens were immediately scanned with a microtomographic unit (SkyScan 1174, Kontich, Belgium) operating with the following parameters: voltage of 50 kv, current of 800 µA, voxel size of 19.76 µm and rotation of 360°. Then, the specimens were immersed in Falcon tubes containing 2ml of phosphate-buffered saline (PBS) solution and stored in a humidified chamber at 37°C for 7 days. After this period, the specimens were removed from the tubes and scanned again according to the same acquisition pattern used for initial verification[25]

Image reconstruction was performed by using NRecon software (V1.6.9.4; SkyScan, Belgium) and the 3D reconstructed images (Figure 1) were analysed by using CT Analyser software (V1.13.5.1; SkyScan, Belgium). As for the total lost volume, the final volume was subtracted from the initial volume in each specimen. The percentage of solubility was calculated by dividing the volume lost by the total volume.

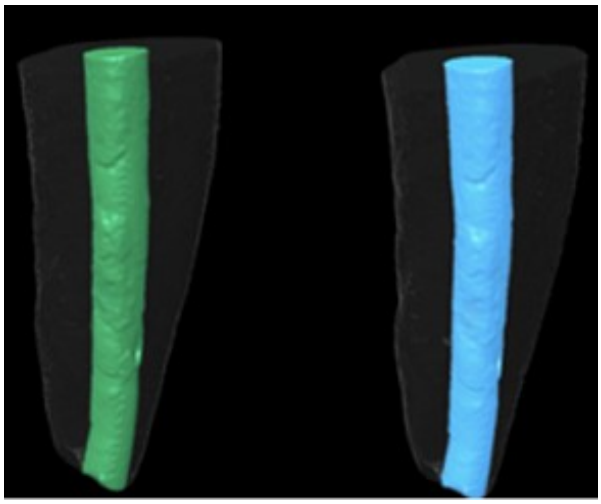

Figure 1. Representative image of a 3D reconstruction of the root canal.

Flow Assessment

The materials were prepared and handled according to the manufacturers' recommendations in an environment with controlled temperature (23 ± 20°C) and humidity (50 ± 5%) (Especificação ADA, 2008). After manipulation (3 minutes), 0.1 ± 0.05 ml of each group was placed individually at the center of a labeled glass plate measuring 75mm x 75mm x 5mm and weighing 83.2 g. Next, another glass plate identical to the previous one was placed under the material, adding a weight of 87.37g to the set and totalling a final weight of 170.57g. After 7 minutes, the additional weight was removed. After this period, the major and minor diameters of the resulting discs were measured by using a digital calliper (Mitutoyo MTI Corporation, Tokyo, Japan). When a difference of less than 1mm between the diameters was observed, the mean value was recorded. All groups were tested five times and the flow was calculated based on mean diameters.

Radiopacity Assessment

Five acrylic plates (2.2cm x 4.5cm x 1mm) with six wells (1mm in depth and 5mm in diameter each) were used, in which each well was filled with the materials from each experimental group. Five radiographic views were taken with size #2 phosphor plates (3cm x 4cm) at a distance of 30cm from them, exposure time of 0.2s, 70 kVp and 8 mA. During the exposure, the acrylic plates containing the materials were positioned together with a scale made of 1100 alloy aluminum with thickness ranging from 1 to 10mm. The phosphor plate was processed immediately after exposure. The images were analysed by using Image J software for Windows 5.1 and radiopacity was determined by radiographic density, converted into mm of aluminum.

Statistical Analysis

As for radiopacity and flow, parametric data were subjected to one-way ANOVA, whereas Tukey's test was used for multiple comparisons. As for solubility, exploratory

analysis used squared transformation to meet the assumptions. Analysis was performed by mixed models with measures repeated in time by using the PROC MIXED procedure of the SAS software. All the analyses were performed by using the SAS statistical software (Ref: SAS User's Guide: Statistics, version 9.4. Cary, NY, SAS Institute Inc 2001) at a significance level of 5%.

Results

Table 1 shows the values of the solubility means (mm^3) before and after 7 days immersed in PBS solution in a humidified chamber at 37°C. CH/ZnO/CHX group had the highest solubility mean, but not statistically different ($p>0.05$) from that of Calplus and Calen/ZnO groups. Moreover, the CH/ZnO/CHX group showed the smallest mean difference before and after immersion in PBS solution, indicating that the group had less volume loss compared to the other groups. We could not quantify the amount of material present in root canals filled with Calen® due to its density, which is very similar to the dentin density.

Table 1. Mean values and standard deviation of solubility (mm^3) as a function of groups before and after treatment.

Group	Before	After	Difference	Multiple comparisons
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Calen®	N/A	N/A	N/A	N/A
Calen/ZnO	20.21 (1.64)	19.09 (1.73)	1.12 (0.65)	19.65 (1.72) ^{AB}
CH/ZnO/CH	22.67 (1.79)	21.67 (1.25)	1.00 (0.87)	22.17 (1.57) ^{A}
Calplus®	21.56 (1.58)	20.35 (2.40)	1.21 (1.05)	20.96 (2.05) ^{A}
Ultracal® XS	18.99 (2.34)	16.89 (2.29)	2.10 (1.51)	17.94 (2.47) ^{B}

Note: Means followed by different letters differ from each other ($p\leq0.05$).

Table 2 presents the mean values of the flows of the tested materials. Calen® had the highest mean flow, with a statistically significant difference ($p\leq0.05$) between all groups. On the other hand, CH/ZnO/CHX group showed the lowest mean flow compared to the other groups.

Table 2. Mean values (mm) and standard deviation of material flow.

Group	Mean	Standard Deviation
Calen®	28.5367 ^{A}	0.4149
Calen/ZnO	19.18 ^{B}	0.3025
CH/ZnO/CHX	16.7933 ^{C}	0.1422
Calplus®	25.345 ^{D}	0.19
Ultracal® XS	19.69 ^{B}	0.518

Note: Means followed by different letters differ from each other ($p\leq0.05$).

Table 3 shows the values obtained during radiopacity test. Calplus® was the material showing the highest radiopacity, but with no statistical difference compared to CH/ZnO/CHX (p> 0.05). The material with the lowest radiopacity was Calen®, with a statistically significant difference (p≤ 0.05) compared to the other materials.

Table 3. Mean values and standard deviation of radiopacity (mmAl) as a function of the groups.

Group	Mean	Standard Deviation
Calen®	0.91 ^{D}	0.08
Calen/ZnO	3.84 ^{BC}	0.26
CH/ZnO/CHX	4.76 ^{AB}	0.35
Calplus®	5.24 ^{A}	0.59
Ultracal® XS	3.70 ^{C}	0.79

Means followed by different letters differ from each other (p≤0.05).

Discussion

Dental trauma mostly affects children aged from 7 to 12 years, being one of the main aetiologies for pulp necrosis of teeth with incomplete root formation[26]. Treatment of these dental elements represents a clinical challenge, especially because of the presence of thin and fragile root walls, reduced root length and wide apex, which can cause extravasation of the endodontic materials used during decontamination and filling of the root canals[27].

Apexification involves cleaning the root canal and successive changes of calcium hydroxide-based medication until formation of a mineralized barrier allowing definitive filling of the tooth[28]. However, this procedure has some limitations, such as long time required to obtain a calcified barrier, ranging from 6 to 24 months; porous barrier without continuous consistency; and the need for two or more sessions, possibly allowing recontamination as a result of several changes of medication and provisional sealing, depending on the patient's cooperation to return to consultations[29]

Furthermore, intracanal medications must have desirable properties, such as antimicrobial effect, biocompatibility, broad spectrum of action, adequate filling, adherence to the root canal walls, non-water solubility and resorbability, in addition to being easily inserted inside the root canal and removed if necessary[25] This study evaluated intracanal medications commonly used in endodontics, but one cannot refrain from emphasizing that Callen paste (used in the present study) is no longer produced by the manufacturer, although it had been used in previous studies elsewhere[30,31,32]. We believe that there is an increasing necessity for replacing medications to be discontinued.

The association of calcium hydroxide, 2% chlorhexidine gel and zinc oxide, also used in the treatment of apexification, has shown good results in case reports, mainly of traumatized teeth[4,19,20,33]. Buck et al.[34] conducted a study on the use of filling paste in re-implanted teeth, in which CH/ZnO/CHX- based medication remained in the root

canals for two years, with the authors reporting that clinical and radiographic signs were observed before and after its insertion. The results showed a significant reduction in periradicular radiolucency and inflammatory resorption.

Many studies evaluate the solubility of an endodontic material to verify its integrity inside the root canal over time, showing that the lower the solubility, the more durable the material[9]. Different vehicles (i.e. aqueous, viscous and oily) have different levels of solubility, with aqueous pastes having higher values and oily ones having lower values[9]. In the majority of the studies assessing endodontic materials, the methods used to determine the solubility are based on weight difference obtained before and after they were placed in ultrapure water[35,36]. The calcium hydroxide present in the medications has hydroscopic property, which can directly influence the results and thus cause an increase in the final weight[7]. Based on a new methodology proposed using mineral tri-oxide aggregate, the solubility of CH/ZnO/CHX-based medication was measured by using microtomographic images in order to determine the volume loss of the pastes in different intervals of time[37,38].

Studies have reported that aqueous, viscous and oily vehicles have different levels of solubility[39], with aqueous pastes showing higher levels and oily ones lower levels, according to chemical analyses of Ca2+ and OH- ions released from the calcium hydroxide paste. The material with the lowest volume loss (mm^3) was the CH/ZnO/CHX-based medication, even though it is a water-soluble and viscous material. This may occur due to the dryness of the paste manipulated with water-soluble vehicles, probably reducing the release of ions and the solubility. Moreover, hydration may have a greater influence on solubility than the type of vehicle itself[7]. Ultracal XS had the highest solubility, probably due to its aqueous vehicle provided by the manufacturer, which is corroborated by previous studies suggesting that hydrophilic particles (nm) present in the material are associated with higher solubiity[40]. Therefore, more studies based on this same proposal should be carried out for more conclusive results.

One of the important properties that must be present in intracanal medications is an adequate flow so that the material can fill the entire root canal and its irregularities. Thus, several methodologies are described in the literature, with the most used being the recommendations of the American Dental Association (ADA), specification no. 57/2000, which is used for endodontic cements. In our study, Calen® paste presented a higher flow rate, which was statistically different from the other groups. However, we must always keep in mind that a higher flow also increases the possibility of extravasation into the periapical region, which may lead to postoperative complications[41]. CH/ZnO/CHX-based medication had the lowest flow rate, statistically differing from the other groups. In this sense, flow rates are influenced by powder particles and amount of liquid vehicle depending on the application of an initial force greater than the gravity[42]. Studies describe that zinc-oxide materials can cause irregularities/reduction in the flow of the material, depending on the ratio[42,43].

Radiopacity is an important physical property, being essential to observe during treatment whether the root canal has been completely filled on radiographic examination. To make it possible to compare the results of radiopacity, an aluminum

scale was used as a standard because it has a linear absorption coefficient similar to that of dental enamel[44]. In this study, CH/ZnO/CHX-based medication and Calplus® paste presented the best results for radiopacity, whereas Calen® paste showed the lowest radiopacity. This difference can be justified by the presence of radiopacifying materials at different concentrations[45]. Zinc oxide is the radiopacifier present in the CH/ZnO/CHX-based medication, which has been evaluated as a chemical compound used to enhance the anti-microbial effectiveness of calcium hydroxide and radiopacity. However, size and molecular weight can interfere with physical and biological properties[46]. Iodoform and barium sulphate are the radiopacifier, respectively, for Calplus® and Ultracal XS pastes. The authors point out that iodoform has good radiopaque properties due to its high atomic weight, but which can vary depending on its ratio[47]. Calen® paste also has zinc oxide in its composition, but in a lower percentage, which is probably the reason why its radiopacity was lower compared to the other materials studied.

This study shows the importance of evaluating the physical properties of recent materials studied in the literature, such as CH/ZnO/CHX-based medication, by comparing the brands already established in the market. However, the lack of standardization of the tests for intracanal medications was a limitation of our study. For this reason, test standardization has been adjusted for endodontic cements, which may generate doubts and even methodological difficulties. Further *in vivo* and *in vitro* studies should be carried out to confirm the results.

Within the limitation of this study, it can be concluded that the filling pastes evaluated presented characteristics like those of other medications available in the market, thus representing a viable and cheap alternative to be used in cases of apexification of traumatized teeth.

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Data availability statement

The resulting data supporting the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interest statement

The authors do not have any financial interest in the companies whose materials are included in this article.

Authors contribution

Patrícia Almeida da Silva de Macedo: Analysis and interpretation of data, drafting the manuscript, final approval.

Walbert de Andrade Vieira: Analysis and interpretation of data, drafting the manuscript, final approval.

Paulo Henrique Gabriel: Analysis and interpretation of data, drafting the manuscript, final approval.

Karla de Faria Vasconcelos: Acquisition of data, analysis and interpretation of data, drafting the manuscript, final approval.

Francisco Haiter Neto: Conception and design, drafting the manuscript, final approval.

Ana Carolina Correia Laurindo de Cerqueira Neto: Conception and design, acquisition of data, analysis and interpretation of data, drafting the manuscript, final approval.

Brenda Paula Figueiredo de Almeida Gomes: drafting the manuscript, final approval.

Marcos Frozoni: drafting the manuscript, final approval.

Adriana de-Jesus-Soares: Conception and design, analysis and interpretation of data, drafting the manuscript, final approval.

Ethics statement

Not applicable.

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