

Root Canal Penetration of a Sodium Hypochlorite Mixture Using Sonic or Ultrasonic Activation

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The purpose of this *ex vivo* study was to determine, in "open" and "closed" systems, whether the design has an influence on the penetration length of sodium hypochlorite mixed with a radiopaque contrast medium, measured in millimeters, when delivered using positive pressure (PP) and using sonic (SI) or passive ultrasonic (PUI) activation. Sixty single-rooted teeth were divided into two groups: open and closed systems (n=30). Root canal shaping was performed to a working length of 17 mm. The samples were divided into three sub-groups (n=10) according to irrigant delivery and activation: PP, and SI or PUI activation. By using radiographs, penetration length was measured, and vapor lock was assessed. For the closed group, the penetration distance means were: PP 15.715 (± 0.898) mm, SI 16.299 (± 0.738) mm and PUI 16.813 (± 0.465) mm, with vapor lock occurring in 53.3% of the specimens. In the open group, penetration to 17 mm occurred in 97.6% of the samples, and no vapor lock occurred. Irrigant penetration and distribution evaluation using open and closed systems provide significantly different results. For closed systems, PUI is the most effective in delivering the irrigant to working length, followed by SI.

Key Words: root canal
irrigation, ultrasonic, sonic,
positive pressure, activation.

Introduction

Sonic and ultrasonic irrigant agitation devices have been initially suggested in root canal treatment to enhance debridement after shaping. Their differences in oscillation frequency reflect on tip movement amplitude and subsequent oscillating pattern, with the latter having higher frequencies (>20 kHz) but lower amplitudes (1). Ultrasonic irrigation without simultaneous root canal instrumentation, by aiming for the file not to bind the root canal walls, has been termed Passive Ultrasonic Irrigation (PUI) (2), although the term "Ultrasonically Activated Irrigation" has been proposed recently, as file-to-wall contact nonetheless occurs (3).

The root canal system is normally a closed-end canal, as the roots are usually embedded in the periodontal tissues and the alveolar bone (4), although certain pathways of reduced resistance towards soft tissues, such as periapical lesions, perforations or direct communication with the maxillary antrum, have been suggested (5). Further exceptions are selected endodontic surgery procedures such as periradicular surgery with a "through and through" approach, replacement surgery, and preparation for corrective surgery in teeth where the root has lost a great amount of bone support. The clinical significance of irrigants reaching the most apical part of the root canal is related to the fact that the management of teeth with apical periodontitis aims to disrupt the biofilms in this area, as surviving microorganisms are associated with treatment

failure (6). Furthermore, the presence of incompletely treated pulp tissues is suggested as a potential cause of persistent pain in vital cases (7).

The effects of gas entrapment on root canal debridement have been demonstrated *in vitro* using "closed" and "open" system designs. These investigations found that apical vapor lock had adverse effects, and questioned the clinical relevance of conclusions derived from assays where the fluid flow through the apical foramen is not adequately restricted (8). Although several investigations have looked into the effect of activation in terms of the ability of irrigants to reach working length (WL), only recently *ex vivo* models have emphasized the role of closed systems, and a dichotomous approach whereby the irrigant "reaches the WL" or "does not reach the WL" has been used. Additionally, to the best of our knowledge, no investigation has directly compared irrigant penetration length *per se* in "open" and "closed" systems. Current techniques for evaluating irrigant penetration and distribution include direct observation of cleared teeth *ex vivo* (9-13) or radiographic contrast *ex vivo* (9,10), *in vivo* (2, 13-5), as well as simulated plastic canals (16).

The purpose of this *ex vivo* study was to determine, in "open" and "closed" systems, whether system design has an influence on a NaOCl-containing contrast solution penetration length measured in millimeters and vapor lock formation, when delivered using positive pressure (PP) and sonic (SI) or passive ultrasonic (PUI) activation.

Material and Methods

Sixty single-rooted upper incisor teeth were used in this study. Teeth were kept for two h in 4% NaOCl, and any visible calculus was removed ultrasonically. The presence of a single canal was verified radiographically by taking three angulated films and by direct exploration under a dental operating microscope (OPMI Pico Dental Microscope; Carl Zeiss, Oberkochen, Germany). All experimental procedures were performed by the same operator. The patency of the root canals was obtained using a 10 K-file (Maillefer, Ballaigues, Switzerland), and root length was standardised to 18 mm.

The specimens were randomly allocated to 2 groups: Group 1. Closed system (n=30). The root apex was covered with paste-paste adhesive (Pattex Extrem-Pro Henkel, Düsseldorf, Germany) (Fig. 1A and 1B), prepared according to the manufacturer's instructions, to achieve a fluid tight seal. Group 2. Open system (n=30). The apical foramen was left uncovered (Figs. 1C and 1D).

Root canal shaping was performed to a working length (WL) of 17 mm, using Profile rotary files (Maillefer) of up to 30 size 0.06 taper. During this instrumentation, all samples received 1.5 mL of 4.25% NaOCl, which was delivered between each instrument by using a 30G Max-i-Probe (Dentsply-Rinn, Elgin, IL, USA).

Following instrumentation, a coronal reservoir of wax (Hygienic; Coltène/Whaledent, Altstätten, Switzerland) was made to resemble the pulp chamber and retain the irrigant solution (Figs. 1B and 1D). Subsequently, samples were randomly allocated to 3 sub-groups according to the irrigation delivery system: Subgroups 1A and 2A (n=10 each). Using a 30G Max-i-Probe (Dentsply-Rinn) at WL-2 mm. Subgroups 1B and 2B (n=10 each). Using the

Endoactivator (Advanced Endodontics, Santa Barbara, CA, USA) with a 25/.04 tip, set at 10000 cycles per minute per 30 s, placed at WL-2 mm. Subgroups 1C and 2C (n=10 each). Using an untapered Irri-S tip size 25 (VDW GmbH, Munich, Germany) mounted on an Ultra ultrasonic unit (VDW), set

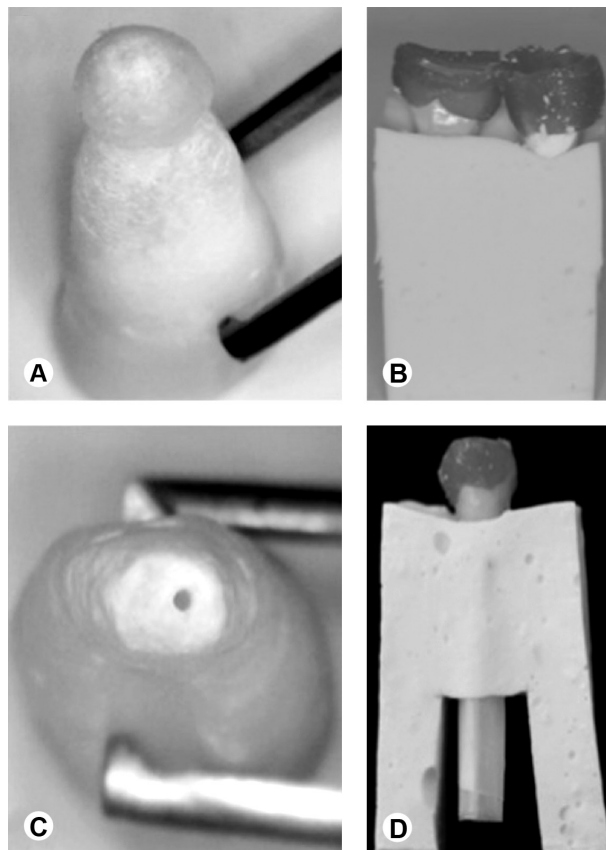


Figure 1. Closed system (A). Closed system mounted in alginate (B). Open system (C). Open system mounted in alginate (D).

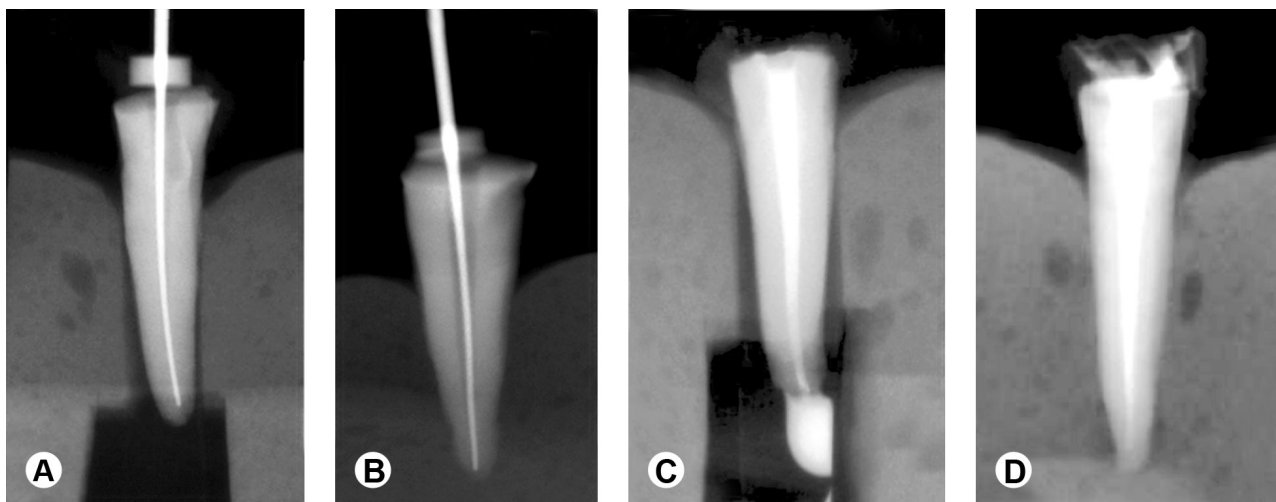


Figure 2. Working length confirmation radiographs (A,B). Open system specimen post-irrigation radiograph showing irrigant extrusion (C). Closed system specimen post-irrigation radiographic image showing irrigant penetration (D).

at power 25 (Irri-mode) for 30 s, placed at WL-2 mm.

The final irrigation sequence was as follows: 1.5 mL of 4.25% NaOCl followed by 1.5 mL of 17% EDTA, and a final rinse with 4.25% NaOCl at 2 mm from the WL, using the Max-i-Probe.

The canals were then dried using paper points, and the teeth mounted in alginate (Zhermack, Badia; Polesine, Italy) blocks with standard dimensions (Fig. 1B). For the open system group, the external surface of the root was protected with adhesive tape (Fig 1D).

Contrast Solution Preparation and Irrigant Penetration Evaluation

A radiograph in bucco-lingual direction with the master apical file (MAF), a size 30 K-Flexofile (Dentsply-Maillefer) (Figs. 2A and 2B), was exposed to confirm that the MAF reaches the desired WL (X Mind 40 cm Satelec, Madrid, Spain).

The contrast solution was prepared by mixing 40% Iomeron 300® (Bracco, Milan, Italy) and 60% 4.25% NaOCl. Pilot studies carried out prior to the main investigation showed a better visualization of the contrast with this ratio.

One milliliter of the contrast solution was delivered at WL-2, using a Max-i-Probe 30G syringe, and left *in situ* for 30 s. For subgroups with sonic and ultrasonic activation, the solution was then agitated for 30 s, with the tips placed at WL-2 mm.

A second radiograph, following irrigation with the contrast medium, was exposed (Figs. 2C and 2D), with consistent angulation, direction and distance of x-ray beams, when compared with the MAF image. The radiographic apparatus settings were maintained unchanged during the study.

Evaluation Criteria

To measure the depth of contrast penetration, the software Photoshop Extended CS5.1. version (Adobe Systems Incorporated, San Jose, CA, USA) was used to

process radiographic images. The ruler tool was selected to obtain a customized scale of 17 mm by calibrating the length of the MAF in the first radiograph of each sample. Then, based on this scale, the penetration length was measured in mm in the matching post-irrigation images.

Finally, post-irrigation radiographs were assessed for vapor lock. The samples were scored by a trained evaluator who was blinded for subgroup assignments pertaining to each sample, but not to the type of system, because of the obvious differences in radiographic image.

Statistical Analysis

The χ^2 test was used to analyze qualitative variables. For quantitative variables, the Kruskal-Wallis and Mann-Whitney U-test were used. The level of significance was set at $p < 0.05$. Statistical analysis was performed using SPSS 15.0 for Windows (SPSS Inc., Chicago, IL, USA).

Results

Irrigants Penetration Depth

In the open systems, 17 mm (full WL) was reached in 97.6% of the samples, the only exception being a single sonically activated specimen, in which a length of 16.9 mm was reached. No statistically significant differences were found between the subgroups.

In closed systems, 17 mm was reached in 43.3% of the samples, with statistically significant differences when compared to the open systems ($p = 0.001$). Statistically significant differences between the closed system subgroups were shown ($p = 0.020$) only between PP and PUI (Table 1).

Vapor Lock Analysis

In the open systems, no sample presented with vapor lock. In the closed systems, 53.3% of the roots presented with vapor lock overall. No statistically significant differences were found between the subgroups ($p = 0.169$) (Table 1).

Discussion

NaOCl activation with sonic and ultrasonic means has previously been shown to be more efficient at irrigant replacement at the apical third, by breaking the vapor lock and moving the solutions apically and laterally in closed systems *ex vivo* (9). The present results are in concordance with investigations using closed systems when comparing similar delivery and agitation methods (2,4,10). An *in vivo* investigation, using a radiopaque irrigant, showed that PUI is more effective than a conventional syringe in delivering this solution to WL, with mean distances from the WL of 0.21 mm and 1.51 mm respectively (2); similarly, our investigation suggested means of 0.187 and 1.287

Table 1. Irrigant penetration depth and vapor lock percentage of the closed systems subgroups

Subgroup	n	Mean solution penetration depth (mm) \pm SD	Vapor lock (%)
Positive Pressure	10	15.715 \pm 0.898 ^a	70
Sonic activation	10	16.299 \pm 0.738	60
Passive ultrasonic activation	10	16.813 \pm 0.565 ^b	30

Groups identified by different superscript letters indicate significant statistical difference in regards to irrigant penetration ($p = 0.020$). No significant differences were found in regards to vapor lock percentage ($p = 0.169$). SD: standard deviation.

mm for these groups. The penetration of NaOCl *in vitro* has previously only been looked at as a "binary variable". An investigation using cleared teeth showed that positive pressure is extremely unsuccessful in delivering irrigants to the WL, whilst in 40% of those activated with SI and 65% of those activated with PUI, the irrigant reached WL (4). When comparing different canals prepared to tapers 0.04 or 0.08 using a radiographic contrast, 66.7-73.3% of the samples activated with PUI and 20-47.7% of the samples activated with SI reached WL (10). In our study, the same apical preparation size was aimed for, and a 0.06 taper was achieved, with the contrast irrigant reaching the full WL in 43.3% of the closed systems samples.

Our results confirm the differences between closed and open systems in regards to vapor lock formation *in vivo* (2,13-5) and *in vitro* (8). A recent investigation, using transparent resin blocks and a computational approach, found vapor lock formation in 48% of the cases (11), similar to our 53.3% value. It is worth mentioning that apart from vapor lock, differences in irrigant flow between open and closed experimental models may explain the dissimilarities in the observed irrigant penetration (11).

The use of non-cleared teeth aims to prevent chemical modifications of the dentine, in order to allow a larger degree of gas bubble formation because of interaction with NaOCl. In the absence of organic matter, gas bubbles are not readily formed because of its degradation with NaOCl. Therefore, simulated plastic canals, and possibly cleared teeth, mostly take into account the air originally entrapped by the solution. A similar problem occurs if radiopaque mixtures do not contain NaOCl. *In vitro* simulated plastic canal models have previously been criticized, as the samples may act differently to dentine due to the dentin's porous nature, the presence of complicated morphology (17), and because of the hydrophobic surface of the plastic (5). Furthermore, *in vivo* investigations have used radiopaque solutions to evaluate irrigation dynamics (2,13-5), with the detection of radiopaque solutions *in vitro* suggested to be more predictable because of the lack of anatomic interference (13).

It is worth mentioning that several physical characteristics of the mixtures which are used to visualize root canal penetration are dissimilar to those of commonly used irrigants, and this may have an influence on their rheology (18). Therefore, the flow of unmixed NaOCl can be different in clinical reality when compared to experimental models. Further understanding of the role of surface tension and viscosity of root canal irrigants, and their relevance with regards to flow when in contact with a moist surface such as dentine, is required (18).

Several procedures have been advocated to improve irrigation dynamics in regards to vapor lock and apical

penetration. Apical patency is associated with an improvement in apical delivery and an overall reduction of gas bubble presence *in vivo* (13-5). Basic research investigations suggest that the use of apical negative pressure predictably irrigates the canals to the full WL (4,12). Root canal preparation apical size influences taper lock size (11), whilst in curved canals, preparation taper affects the ability of sonic irrigation to deliver NaOCl to the full length, whilst it has no influence for PUI (10). Finally the insertion of the needle tip up to WL, or by increasing the irrigant flow rate, allows the established vapor lock to be reduced *in vitro* (11). From these results, it may be concluded that overall, *ex vivo* irrigant penetration and distribution evaluation using open and closed systems gives significantly different results. For closed systems, agitation PUI is most effective in delivering the irrigant to WL, followed by SI. PP delivery was the least efficient irrigation method.

Resumo

O objetivo deste estudo *in vivo* foi determinar, para os sistemas "abertos" e "fechados", se o design tem influência na penetração, em milímetros, do hipoclorito de sódio misturado com um meio radiopaco quando empregado na ativação com pressão positiva (PP) e ativação sônica (SI) ou ultrassônica passiva (PUI). Sessenta dentes unirradiculares foram divididos em dois grupos: sistema aberto e sistema fechado (n=30). Os canais radiculares foram trabalhados até um comprimento de trabalho de 17 mm. Os grupos foram subdivididos em três subgrupos (n=10) de acordo com a solução irrigadora e a ativação: PP, e ativação SI ou PUI. Usando radiografias, a distância de penetração foi medida e avaliado o vapor contido. Para o grupo fechado, as distâncias médias de penetração foram PP 15,715 (±0,898) mm, SI 16,299 (±0,738) mm e PUI 16,813 (±0,465) mm e houve vapor contido em 53,3% das amostras. No grupo aberto, houve penetração de 17 mm em 97,6% das amostras, sem contenção de vapor. A penetração do irrigante e avaliação da distribuição usando sistemas aberto e fechado produziram resultados significativamente diferentes. Para os sistemas fechados, PUI é mais eficaz para levar o irrigante até preencher o comprimento de trabalho, seguido por SI.

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