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CBCT-Based Assessment of Vapor Lock Effects on Endodontic Disinfection

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Abstract: Background: The phenomenon of vapor lock, characterized by the formation of gas bubbles, poses challenges in achieving effective cleaning and debridement during endodontic treatments. This study aimed to evaluate the presence of vapor lock and to quantify its volume in the root canal system. Methods: Ten single-rooted teeth were selected, and their root canals were shaped using the Protaper Next system and irrigated with 5% NaOCl and 17% EDTA. Then, the canals were irrigated with a solution made of contrast medium (8 M cesium chloride solution) mixed in equal proportions with 5% sodium hypochlorite. CBCT scans were performed to analyze the presence and volume of bubbles in different canal thirds. Statistical analysis was conducted to compare the number of bubbles and the percentage of space occupied by them. Results: The results demonstrated the presence of vapor lock in all treated teeth, with a higher concentration of gas bubbles in the apical canal third. The formation of gas bubbles hindered the cleaning and debridement procedures, particularly in the apical region. Conclusions: This study provides evidence of the occurrence of vapor lock and highlights the importance of enhancing the cleaning phase in endodontic treatments to minimize bubble formation or eliminate them once formed. These findings contribute to a better understanding of the challenges posed by vapor lock and suggest avenues for optimizing endodontic procedures.

Keywords: vapor lock; root canal; air entrapment; irrigation; sodium hypochlorite; gas bubbles; micro-CBCT

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1. Introduction

Cleaning, shaping, and three-dimensional obturation of the root canal system represent the goals of modern endodontics [1,2]. The mechanical action of endodontic instruments on the canal walls and the chemical action of the irrigating solutions provide the necessary cleaning for the elimination of pulp tissue, microorganisms, and their metabolic products [3–6]. The essential role of shaping is to create the conditions for effective penetration of the irrigants, achieved through activation techniques, to remove organic and inorganic content and break down the bacterial load, even in the anatomical complexities of the endodontic system [7–10]. Microorganisms remaining in the endodontic space at the end of the treatment could potentially recolonize the root canal system by exploiting any residual pulp tissue as a source of nourishment. In fact, the presence of infected necrotic tissue within the canals after treatment represents the main cause of endodontic failure [11–13].

According to the literature, approximately half of the endodontic system is untouched by instruments, emphasizing the crucial role of chemical cleaning [3,14–16]. Irrigants need to come into direct contact with the entire volume of the endodontic system to ensure effective action [1,9,15]. Recently, concerns have been raised regarding the ability of irrigants to reach the apical portion of the canal system due to the possible formation of gas bubbles known as vapor lock [1,14,17–19]. The root canal system is normally a closed-end canal, as the roots are embedded in periodontal tissues and the alveolar bone, although pathways of reduced resistance towards soft tissue can be present, such as canal communications with the maxillary sinus, root perforations, or periapical lesions [20–22]. This particular anatomical condition can contribute to the trapping of gas at the apical end of the canals, leading to the occurrence of the vapor lock effect during irrigation [22–28]. Vapor lock is caused not only by physical factors but also by chemical factors, such as the release of CO_2 from necrotic pulp tissue dissolved by NaOCl [5].

Small bubbles that are completely surrounded by an irrigant or only partially in contact with the root canal walls are mobile and cannot block the penetration of the irrigant into any part of the root canal [29,30]. However, these bubbles may coalesce, forming a column of gas into which further fluid penetration is impossible. Passing endodontic instruments through this bubble does not result in its removal or reduction [15,18,19]. The presence of bubbles could prevent the deep penetration of any irrigant, thereby affecting the effectiveness of debris removal and cleaning [17,18]. Failure to clean and debride the apical portion due to vapor lock can result in the failure of endodontic therapy [5].

The objective of this research is to evaluate the presence of vapor lock during endodontic treatment in vitro and to quantify its amount.

2. Materials and Methods

2.1. Experimental Design

Ten single-rooted teeth extracted for periodontal reasons were selected. The teeth were subjected to two-dimensional radiography (RVG CS 6200, Carestream Health, Inc., Rochester, NY, USA) to verify the presence of a single root canal. Two teeth were excluded due to the presence of two canals.

The selected teeth were decrowned at 17 mm from the anatomical apex, and canal patency was confirmed with a size 10 K-file. Following a protocol described in the literature to simulate a closed-end canal system, the middle and apical thirds of the roots were coated with adhesive (Universal Tray Adhesive, Zhermack SpA, Badia Polesine, Italy) [17]. Subsequently, each sample was placed inside a transparent Plexiglas tube filled with polyvinylsiloxane (Affinis Putty Soft, Coltene/Whaledent, Altstatten, Switzerland) [19].

Each root was shaped at the working length (17 mm) using the Protaper Next system (Dentsply, Maillefer, Ballaigues, Switzerland) up to the X3 file (30/07). After each instrument (X1, X2, and X3), the canal was irrigated with 1 mL of 5% NaOCl using a 30 G needle positioned 1 mm from the working length. NaOCL was delivered at the rate of 1 mL/30″. After the shaping phase, irrigation with 5 mL of 17% EDTA was performed using a 30 G needle positioned 1 mm from the working length. EDTA was delivered at the rate of 5 mL/min. Each canal was subsequently irrigated with 5 mL of deionized water and dried with paper points, at the rate of 5 mL/min. Then, the canals were irrigated with a solution made of contrast medium (8 M cesium chloride solution) mixed in equal proportions with 5% sodium hypochlorite using a 30 G needle positioned 1 mm from the working length [31].

Each sample was analyzed with a CBCT scanner (Planmeca ProMax 3D Mid, Planmeca, Helsinki, Finland) to detect the presence of vapor lock. Two researchers from Messina University independently conducted the same analysis, and in cases of discrepancies in the results, a third senior researcher was consulted.

The presence and volume of bubbles in the coronal, middle, and apical thirds of each canal were quantified by evaluating the CBCT scans (Figures 1 and 2).

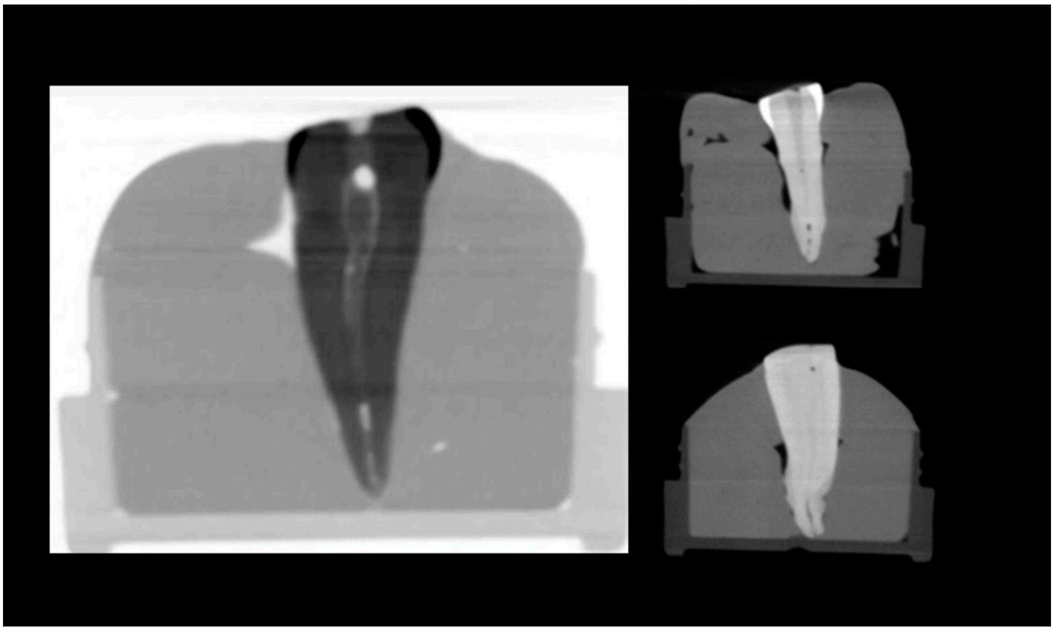

Figure 1. CBCT examination of the samples. Air bubbles and gas columns were present in the canal.

Figure 2. Measurement in CBCT scans.

The volume of each individual spherical bubble was calculated using the formula for calculating the volume of a sphere:

$$V = \frac{4}{3}\pi r^3$$

The volume of the canal and the volume of the gas columns were calculated using the formula for calculating the volume of a truncated cone:

$$V = \frac{\mathrm{A}b + Ab' + \sqrt{\mathrm{Ab} \times \mathrm{Ab}'}}{3}$$

2.2. Statistical Analysis

The root of each samples was divided into 3 parts (coronal, middle, and apical) by dividing the exact size of each sample by 3. The mean and standard deviation of the number of bubbles and the percentage of volume occupied by the bubbles were calculated for each section of the canals (coronal, middle, and apical). The Student's t-test was applied to compare the number of bubbles present in the three root portions and the percentage of space occupied by them. A p-value ≤ 0.05 was considered statistically significant. The statistical analysis was performed using SPSS for Windows version 22 statistical software.

3. Results

The number, mean, and standard deviation (SD) of the bubbles found in the different third of the canals are listed in Table 1.

Table 1. Bubbles number in each sample.

Sample	Bubbles in the Coronal Third (n°)	Bubbles in the Middle Third (n°)	Bubbles in the Apical Third (n°)
1	1	2	3
2	2	1	2
3	0	0	3
4	0	0	2
5	1	0	2
6	1	0	3
7	0	1	0
8	0	0	2
Tot	5	4	17
Mean	0.625	0.5	2.125
SD	0.74	0.76	0.99

Five bubbles were detected in the coronal third of the samples with a mean of 0.625 and a SD of 0.74. In the middle thirds, four bubbles were detected with a mean of 0.5 and SD of 0.76. Seventeen bubbles were detected in the apical third of the samples with a mean of 2.125 and the SD of 0.99.

The average percentage of the volume occupied by bubbles in the coronal, middle, and apical thirds is shown in Table 2.

Table 2. Air percentage in the canal space.

Sample	Volume Occupied in the Coronal Third Expressed in Percentage	Volume Occupied in the Middle Third Expressed in Percentage	Volume Occupied in the Apical Third Expressed in Percentage
1	1.308	15.764	98.881
2	42.151	10.482	98.202
3	0	0	99.010
4	0	0	99.943
5	11.611	0	99.294
6	7.11	0	97.212
7	0	3.897	0
8	0	0	79.22
Tot	7.773	3.768	672.671
Mean	7.773	3.768	84.084
SD	14.54	6.09	34.68

The percentage value of the coronal third is 7.773% with SD equal to 14.54. In the middle third, the percentage is 3.768% with SD 6.09, while in the apical third, the value rises to 84.084% with SD 34.68. Table 3 shows the statistical analysis of the cross comparison between the coronal, middle, and apical third in relation to the number of bubbles found.

Table 3. Statistical analysis of the presence of bubbles (n°) in the canal thirds.

Bubbles (n°)	**t-Student**	***p*-Value**	**Statistical Significance**
Coronal vs. middle	0.333	0.743	No
Coronal vs. Apical	3.433	<0.05	Yes
Middle vs. Apical	3.683	<0.05	Yes

There were no statistically significant differences between the coronal third and the middle third ($p = 0.743$). There was a significant statistical difference between the coronal and apical third ($p < 0.05$) and between the middle and apical third ($p < 0.05$). The cross-comparison relating to the volume occupied by the vapor lock in the different areas of the canal showed a non-significant difference between the coronal and middle third (*p*-value 0.484) (Table 4).

Table 4. Statistical analysis of the volume of bubbles (%) in the canal thirds.

Volume Percentage	**t Student**	***p*-Value**	**Statistical Significance**
Coronal vs. Middle	0.719	0.484	No
Coronal vs. Apical	5.74	<0.001	Yes.
Middle vs. Apical	6.452	<0.001	Yes

There is a statistically significant difference between the coronal and apical third ($p < 0.01$) and between the middle and apical third ($p < 0.01$).

4. Discussion

The first theoretical reports on the effect of gas entrapment in closed systems were by Deutsch, subsequently demonstrated by Pesse [25,32]. Since then, several studies have characterized the phenomenon of vapor lock [1,2,17,19,29].

The root canal system is a closed tubular system at one end, and this anatomical condition is the main cause of vapor lock formation, resulting in the formation of air bubbles that can hinder the irrigation of the canal walls [1,17,29]. The diffusion of the irrigant into the endodontium is influenced by various factors, such as the contact angle established with the surface it flows on, the length and diameter of the root canal system, the flow rate of the irrigant, the delivery technique, and the volume of the solution [19,29,30,32,33]. The position of the tooth can also contribute to the formation of vapor lock; according to Boutsioukis et al., it is easier for gas bubbles to become trapped in the endodontium of upper teeth, while in lower teeth, they are more likely to float and escape [28,29].

In vitro experimentation of the vapor lock effect presents numerous difficulties that could result in procedural biases and compromise the research results. For instance, the size and position of a trapped bubble can change due to sample vibration or temperature variations, which can cause air expansion or contraction [29]. Furthermore, altering the physicochemical properties of the irrigant due to mixing with a contrast medium may affect bubble formation. Lastly, the different characteristics of teeth, such as canal width, length, presence of curves, and position in the arch, can lead to varying results.

Our experimental design, compared to previous ones, not only involved qualitative evaluation but also quantitative assessment, allowing for a more accurate analysis of the vapor lock phenomenon. The authors who used the same protocol to observe the vapor lock phenomenon evaluated only the presence of bubbles and whether the phenomenon occurred or not [17,30]. Our protocol instead envisaged the measurement of the number of bubbles and the measurement of the volume; therefore, the extent of the vapor lock. The methodology used and the results obtained, following the advice of the authors, can serve as a basis for further evaluations of various techniques aimed at improving root canal irrigation.

The results of our research demonstrate the presence of vapor lock in all the teeth that underwent endodontic treatment, as has been confirmed in the literature [30,34]. The bubbles mainly occupy the apical third. In this root portion, gas bubbles occupy most of the canal volume, thus hindering the cleaning and debridement procedures. As previously demonstrated by other authors, cleaning procedures are less effective in the apical third compared to the coronal and middle thirds [35–39]. Samples three, four, and five exhibit a column of gas. In line with the physicochemical mechanisms of vapor lock formation, multiple gas bubbles can merge to form a larger column [17,19]. In light of the results obtained, it becomes even more apparent that clinical strategies should be used to improve the cleaning phase and reduce the formation of vapor lock. The literature suggests techniques such as the activation of irrigants, proper maintenance of apical patency, or the use of negative pressure irrigation to minimize the formation of air bubbles during endodontic therapy [17,18,22,29,34,40–42].

Limitation

There are several limitations to our research. Firstly, the canal irrigant was mixed with a contrast medium at a 1:1 ratio. Although the physical characteristics of the contrast medium used are similar to those of sodium hypochlorite, this change in irrigant composition could result in intrinsic changes in its physical properties, such as density, viscosity, surface tension, and contact angle at the root canal walls [41]. This alteration in irrigant composition may affect the formation and behavior of gas bubbles.

Furthermore, the cleaning procedure itself can introduce changes to the tooth tissues. It has been observed that the root canal dentin surface becomes less hydrophilic and exhibits a higher irrigant contact angle compared to intact dentin [29]. These changes can influence the behavior of gas bubbles within the canal.

Another limitation is that once the gas bubbles are formed, they do not maintain a fixed position. The movement of these gas bubbles within the canal can be attributed, in part, to the thickness of the fluid film between the bubble and the canal wall, which is affected by the surface tension and other factors [28,30]. This dynamic nature of gas bubble movement adds complexity to the study of vapor lock.

Furthermore, the authors did not take into account the use of different delivery systems for irrigants other than a classic 30G metallic irrigation needle.

Finally, another limitation is that no power analysis was conducted to establish the exact number of samples; the standard deviation values obtained in this research could be related to the reduced sample size. Further research with a larger sample size will be needed.

It is important to acknowledge these limitations as they can introduce potential biases and affect the interpretation of the results. Future research should consider addressing these limitations and exploring additional factors that may influence the formation and behavior of gas bubbles in the root canal system.

The important point of this article is that it presents a quantitative analysis of the vapor lock phenomenon during endodontic treatments. The study demonstrates the presence of gas bubbles, particularly in the apical third of the root canal system, which hinder the cleaning and debridement procedures. The findings highlight the need for clinical strategies to improve the cleaning phase and reduce vapor lock formation. The authors suggest techniques such as irrigation activation, proper maintenance of apical patency, or the use of negative pressure irrigation to minimize bubble formation.

For further research, it would be valuable to investigate the impact of different irrigation protocols and techniques on vapor lock formation and its consequences. Comparative studies can be conducted to evaluate the efficacy of various cleaning methods in different anatomical complexities in the root canal system. Additionally, exploring the effects of different irrigants and their compositions on vapor lock formation would contribute to the optimization of endodontic treatment outcomes. Long-term studies assessing the clinical implications of vapor lock, such as the success rates of endodontic therapies, could provide valuable insights.

5. Conclusions

Based on the data available to us, it is evident that the vapor lock phenomenon with the formation of gas bubbles occurs in almost all endodontic treatments, especially in the apical canal third. Therefore, the authors recommend enhancing the cleaning phase by implementing clinical procedures that can minimize the formation of bubbles or eliminate them once formed.

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