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A comparative study of the softening abilities of three gutta-percha solvents used during endodontic retreatment

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Abstract

Background: The chemomechanical removal of gutta-percha involves the use of solvents, which serve as an adjunct to mechanical instrumentation during Root Canal Treatment (RCT). The most commonly used solvents for softening gutta-percha are Chloroform and Eucalyptol. Due to some unfavourable properties, their usage in the dental setting is debatable. D-limonene is an essential oil which has fewer undesirable properties when utilised as a gutta-percha solvent.

Objective: This study sought to determine whether D-Limonene had comparable gutta-percha softening properties with Eucalyptol and Chloroform.

Methods: This study was a prospective comparative study. Extracted single-rooted teeth were root-treated using the rotary ProTaper system and stored in normal saline for three months. The teeth were randomly assigned to the three solvent groups, and root-filling removal was performed using K-files and solvents. The median initial penetration depth of the K-file into the softened gutta-percha, the median amounts of additional drops of solvent used, and the median of the total time used to remove all the gutta-percha obturating material from the root canal were statistically evaluated for each of the solvents. The Kruskal-Wallis test was used to compare the medians with the statistical significance set at $p < 0.05$.

Results: D-Limonene utilised the least number of additional drops of solvent ($p < 0.001$) during the gutta-percha removal process, while chloroform utilised the greatest number of additional drops of solvent. There was no statistical difference between the three solvents in the initial penetration depth of the K-file into the gutta-percha and the total time it took to completely remove all gutta-percha from the root canals.

Conclusion: Smaller volumes of D-Limonene produced comparable results as Eucalyptol and Chloroform in the softening and removal of gutta-percha during re-endodontic treatment.

Keywords: Endodontic Retreatment, Chloroform, Eucalyptol, D-Limonene, GUTTA-PERCHA Solvent

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INTRODUCTION

Endodontic treatment aims to thoroughly shape and clean the root canal system to rid it of any infected pulpal tissue or bacteria and to provide a three-dimensional hermetic seal to the root canal system to prevent re-infection [1]. Despite the high success rates of endodontic treatment (85% - 90%), failures do occur [2]. These failures may be attributed to the persistence of bacteria within the root canal system, lack of a hermetic seal during obturation, inadequate condensation of gutta-percha, inadequate

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cleaning and shaping of the canal, coronal leakage or the presence of unidentified accessory canals [3,4].

Treatment options for failed root canal treatment include observing the tooth and doing nothing, extracting the tooth, endodontic retreatment (non-surgical retreatment), and surgical retreatment [5]. These options would usually depend on the cause of root treatment failure, presence and intensity of symptoms, restorability of the tooth, long-term prognosis, cost of retreatment or other treatment modalities, the patient's preferences and the function of the tooth in the mouth [5]. For endodontic retreatment to be successful, all traces of the root-filling materials must be removed from the canal walls to regain access to the apical one-third of the root canal system [6]. Removal of gutta-percha can be carried out by thermal, laser, chemical, and mechanical techniques or a combination of the above [7,8]. Mechanical removal can be carried out with graduated sizes of hand or rotary files with or without the use of solvents [9,10]. In a 2022 study by Ampofo et al., 89.1% of Ghanaian dentists surveyed used mechanical means alone or in combination with chemical solvents to remove gutta-percha material in endodontic retreatment [11]. Using purely mechanical means to remove gutta-percha from root canals may result in root perforation, canal straightening, or alterations in the original canal shape [12].

Gutta-percha is the most widely used root canal filling material throughout the world and has been used for over a hundred years as the main material for the obturation of root canal systems [13]. It is the most common obturation material used by Ghanaian dentists (98.4%) for obturation [11]. Gutta-percha is the dried coagulated tree extract belonging to the genus Palaquium and the family Sapotaceace. These trees are native to Southeast Asia, specifically Malaysia and Indonesia [14]. The Malay terms "GETAH", which means gum, and "PERTJA", which is the name of the tree, were combined to create the name [14]. The composition of dental gutta-percha includes 18.9% to 21.8% gutta-percha, 59.1% to 75.3% zinc oxide filler material, 1.5% to 17.3% metal sulphates which confer radio-opacity, and 1.0% to 4.1% wax and/or resin which act as plasticisers [13,15,16]. In its natural state, gutta-percha exists as 1,4-trans-polyisoprene, which is the trans-isomer of isoprene [17]. The cis-isomer of isoprene is natural rubber. Natural rubber is amorphous, soft and highly flexible in the cis form because the hydrogen atom and methyl group prohibit close packing [16]. Gutta-percha has its methyl groups on either side of the double carbon bond of the isoprene polymer. The repeating units of isoprene monomers that form the gutta-percha are covalently bonded to each other to form polymer chains, which are connected by weak Van der Waals bonds [17].

Solvents are a large group of different chemicals that can solubilise, disperse, or dilute other substances. An ideal gutta-percha solvent should be non-carcinogenic, non-cytotoxic, have a high solvent effect, have a low surface tension, be easy to use, operate quickly, and have a long shelf life [18,19]. Gutta-percha solvents typically act by softening only the gutta-percha component of the gutta-percha cone [20]. The chemical properties of gutta-percha enable its softening and dissolution by solvents. For dissolution to occur, the solute-solvent attractive bonds should be stronger than the intermolecular solute-solute and solvent-solvent bonds [21,22]. When solvents with the same polarity as gutta-percha come into contact with it, they can penetrate the polymer strands and cause their separation. Since gutta-percha is non-polar, weakly polar or non-polar solvents will be more efficient in causing its dissolution [21]. Some organic solvents that have been used to dissolve gutta-percha successfully include chloroform, halothane, xylene, and essential oils such as eucalyptol and orange oil [23,24,25]. Chloroform, Eucalyptol, and D-limonene were found to be the three most commonly used solvents by Ghanaian dentists [11]. Though Chloroform and Eucalyptol are the most widely used solvents in dentistry, they have some undesirable properties. Chloroform has been categorised as a 2B carcinogen by the International Agency for Research of Cancer [26]. Eucalyptol has a pungent odour, which is discomforting to some patients, and it needs to be heated before it can soften gutta-percha maximally [27]. These undesirable properties have led many dentists to turn to alternative gutta-percha solvents from the essential oil family. D-Limonene is refined orange oil [28]. It is safe, biocompatible, has low cytotoxicity, and is non-carcinogenic [28]. In dentistry, it has been used in the dissolution of zinc oxide cemented root-fillings [20,28]. Studies have shown that it exhibits a gutta-percha softening action similar to xylene [20,29]. This study sought to compare the gutta-percha softening abilities of D-Limonene with Chloroform and Eucalyptol.

MATERIALS AND METHODS

Study design and site

This prospective comparative study was performed on 42 extracted maxillary single-rooted whole human teeth that had been extracted because of poor periodontal support. The study was carried out in the Clinical Simulation Laboratory (Phantom Head Clinic) of the Restorative Department of the University of Ghana Dental School (UGDS) at Korle Bu in Accra, Ghana. Adult maxillary central and lateral incisors with lengths between 19 mm and 25 mm were included in the study. Teeth with the following characteristics were excluded from the study: root or crown fractures, the presence of internal or external resorption, caries, root canal or pulp chamber calcifications, dilaceration of roots, open apices, previously root-treated teeth, and cervical tooth surface loss that involved the pulp.

Data Collection

The teeth used in the study were obtained from the Tooth Bank of the Oral Diagnosis and Maxillofacial clinics of the University of Ghana Dental School, Korle-Bu. A total of 42 whole teeth comprising 24 central incisors and 18 lateral incisor teeth were selected. The duration of storage of the teeth in formalin at the tooth bank was unknown. The teeth were transferred into a storage container containing 10% formalin to continue fixing and preserving the tissue's morphology. Formalin is a known tissue preservative that has been used extensively and is internationally accepted in the medical field to fix tissues and preserve tissue integrity. The duration of time tissues are kept in formalin does not affect their morphology [30]. External soft tissue and calculus were manually removed from the tooth surfaces with a universal scaler. A periapical X-ray machine (Carestream CS2 100, Japan) and the paralleling technique were used to obtain digital periapical radiographs. The radiographs were used to confirm the patency of the canals and the absence of internal resorption. The cleaned teeth were subsequently embedded in wax moulds containing a mixture of dental plaster and sawdust to enable easy teeth handling during the root canal procedure.

Initial Endodontic Treatment

Initial Endodontic Treatment was done using the ProTaper Universal Rotary Endodontic Filing Technique [31]. Endodontic treatment of the selected teeth was carried out using the DTE Endo Radar Plus Endodontic Motor (Guilin Woodpecker Medical Instrument Company Limited, China) and ProTaper Universal Files (Dentsply Maillefer, Switzerland) and using the ProTaper crown-down filing technique. Irrigation was done with 2.5% sodium hypochlorite (Milton, Procter and Gamble, United Kingdom) using a size 27-gauge side-vented needle (Eoskyo, Guangzhou, China). Finishing file F1 was used to complete the shaping and cleaning of the lateral incisor canals, and finishing files F1 and F2 were used for the central incisor canals. 17% ethylenediamine tetraacetic acid (EDTA) (Prevest DenPro Limited, India) was used to lubricate the canals during filing and to remove the smear layer. A final irrigation of the canal was done with 2.5% sodium hypochlorite. The canals were dried with paper points (Technical &General Ltd, London, England) and master cones corresponding to the finishing files were lightly coated with Sealapex (Kerr, Italy) and cemented into the canal. The ProTaper Universal gutta-percha cones used were supplied in lengths of 28mm. Excess gutta-percha was removed from the pulp chamber with the use of a heated excavator [32]. The access cavities were restored with Glass Ionomer Cement (Prevest DenPro Limited, India).
The teeth were taken out of the moulds with sawdust and plaster fillings, and post-obturation X-rays were then taken to confirm that the canal spaces were well-obturated and without voids. The root-treated teeth were stored in a normal saline solution at room temperature for three months.

Gutta-Percha Removal

After three months, the teeth were separated into two groups: maxillary central incisors and maxillary lateral incisors. A simple randomisation technique was used to allocate the root-treated teeth into the three solvent groups, i.e., Chloroform (VWR Chemicals BDH, France), Eucalyptol (Silver Bird Eucalyptus oil, Bells, Sons & Co. United Kingdom), and D-limonene (Carvene, Prevest DenPro Ltd. India). At the end of the allocation, each solvent group comprised eight maxillary central incisors and six maxillary lateral incisors. The crowns of the teeth were sectioned with a dental laboratory handpiece and a diamond separating disc to obtain uniform lengths of 18mm as measured from the apex of the teeth. This was done to standardise the root lengths. The residual coronal Glass Ionomer Cement was removed with a high-speed round diamond bur. Removal of the coronal 2 - 3mm of gutta-percha within the canal to create a reservoir for the root canal solvents was done using sizes 1 and 2 Gates-Glidden burs (Henry Schein, Switzerland) [33].

Two drops (10 µL each) of the selected solvent were placed in the created reservoir. The same type of dropping pipette was used for all three solvents to ensure the same amount of solvent was delivered each time. The solvents were left in the created reservoirs for two minutes to allow the solvent to wet the surface of the gutta-percha adequately, soften the gutta-percha, and percolate down the canal [33].

Outcome Variables

After creating the reservoir and inserting two drops of solvent, a timer was set for 2 minutes. After the time had elapsed, a size 20 K-file was used under gentle pressure to penetrate the softened gutta-percha. The depth of initial penetration of the size 20 K-file into the gutta-percha was measured and recorded. The flutes of the file were then cleaned with sterile gauze. The depth of initial penetration was measured in millimetres, and a tally of the results was later done to show which depths occurred more frequently for each solvent used. The timer was reset, and a crown-down instrumentation technique was used to remove the gutta-percha from the root canals, starting with a size of 50 K-file. When resistance to the progress of the file was encountered, the canal was irrigated, and the next lower-sized file was used to remove the gutta-percha. On insertion of the second file and subsequent files, the time continued to be measured. During filing, the indicator for the addition of more drops of solvent was when no softened gutta-percha coated the flutes of the file after insertion into the canal. Debris from filing and softened gutta-percha were rinsed out using 2.5% sodium hypochlorite with a side-vented 27-gauge needle (Eoskyo, Guangzhou, China). During this process, the solvent was replenished as required. The number of additional drops of solvent used was noted and recorded.

Filing to clean the walls with the K-files, followed by irrigation and replenishing of the solvent, continued until there were no more gutta-percha particles on the flutes of the file. A pair of magnification loupes (3.5X, Aries Outlet, China) was used by the operator to examine the file to ensure no traces of gutta-percha were present on the flutes. The canal was then irrigated with 17% EDTA (Prevest DenPro Limited, India) and a final irrigation of the canal was done with 2.5% sodium hypochlorite. The total time to completely remove all gutta-percha from the canal walls was then noted and recorded. The time was not kept constant to simulate real-life clinical settings. This is because, during the retreatment procedure, all the gutta-percha must be removed from the canal before further treatment can be carried out. This was also done to give clinicians an idea of the average length of time for a solvent to completely remove root-filling material from the root canals. The same operator performed the initial root canal treatment and the subsequent removal of the gutta-percha from the root canals. The following outcome variables were measured: 1. The initial penetration depth of the K-file into the gutta-percha. 2. The number of additional drops of solvent required to dissolve the gutta-percha from the root canals. 3. The total time it took to remove all gutta-percha from the walls of the root canals.

Data analysis

Data was captured and cleaned using Microsoft Access 10 (Microsoft, USA). The software that was used for data analysis was SPSS (Statistical Package for Social Science (SPSS) Inc, Chicago, Illinois, USA) Version 22. Frequencies, percentages, medians and interquartile ranges of data were presented as tables. The median initial penetration depth of the K-file, the median number of additional drops of solvent, and the median total of the time used to remove all the gutta-percha were statistically evaluated for the three solvent groups using the Kruskal-Wallis one-way analysis of variance by ranks test.

RESULTS

A total of 42 teeth were used in the study. More than half (57.1%, n = 24) of the teeth were maxillary central incisors, and the remaining teeth (42.9%, n = 18) were maxillary lateral incisors. The teeth were obtained from the tooth bank of the University of Ghana Dental School. Maxillary central incisor and maxillary lateral incisor teeth were used for the study because of the similarities in the shapes of their root canals. The values obtained for the initial penetration depth of the K-file into the softened gutta-percha after two minutes are presented as frequencies and percentages in Table 1. The initial depth of penetration of the K-files into gutta-percha softened with the respective solvents ranged from 2 mm to 16 mm. The frequencies for each depth were recorded for each solvent. Chloroform and eucalyptol had the deepest depth of penetration of 16 mm with frequencies of two each. The deepest depth of penetration for D-Limonene was 14 mm with a frequency of one. The values obtained for the additional drops of solvent used to soften gutta-percha during its removal from the root canals are presented as frequencies and percentages in Table 2.

Additional drops of solvents used for the 42 teeth ranged from 0 to 6, with chloroform utilising the most additional drops of gutta-percha for complete removal and Eucalyptol and D-Limonene having a maximum of three additional drops each. The values obtained for the total time it took to remove the gutta-percha from the root canals are presented as frequencies and percentages in Table 3. An ideal gutta-percha solvent would take the least amount of time to completely remove all the softened gutta-percha from the root canal walls. Time ranges for complete removal of gutta-percha were from 156 seconds to 871 seconds. Eucalyptol took the least time to completely remove gutta-percha (201 - 699 seconds), followed by D-Limonene (157 - 745 seconds). Chloroform took the most time to completely remove the gutta-percha obturation material from the root canal walls (156 - 871 seconds).

Using the Kruskal-Wallis test, no significant difference was observed in the median values for the initial depth of penetration of K-files into the softened gutta-percha ($p = 0.737$) and the total time ($p = 0.180$) it took to remove all the gutta-percha from the root canals across the solvent groups (Table 4). However, there was a significant difference ($p < 0.001$) in the additional drops of solvent used in the gutta-percha removal across the solvent groups. The least drops of additional solvent used were by the D-

Table 1. Initial depth values presented as frequencies and percentages

Initial Depth (mm)	Chloroform		Eucalyptol		D-Limonene	
	Freq.	Percent (%)	Freq.	Percent (%)	Freq.	Percent(%)
2	1.0	7.1	0.0	0.0	5.0	35.7
3	0.0	0.0	1.0	7.1	0.0	0.0
4	0.0	0.0	1.0	7.1	0.0	0.0
5	1.0	7.1	0.0	0.0	0.0	0.0
6	2.0	14.3	0.0	0.0	0.0	0.0
7	2.0	14.3	3.0	21.4	5.0	35.7
8	0.0	0.0	1.0	7.1	3.0	21.4
9	2.0	14.3	2.0	14.3	3.0	21.4
10	1.0	7.1	0.0	0.0	0.0	0.0
11	3.0	21.4	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	1.0	7.1	2.0	14.3
14	0.0	0.0	2.0	14.3	1.0	7.1
15	0.0	0.0	1.0	7.1	0.0	0.0
16	2.0	14.3	2.0	14.1	0.0	0.0
Total	14.0	100.0	14.0	100.0	14.0	100.0

Table 2. Additional drops of solvent used values presented as frequencies and percentages.

Additional Drops (numbers)	Chloroform		Eucalyptol		D-Limonene	
	Freq.	Percent (%)	Freq.	Percent (%)	Freq.	Percent (%)
0	0.0	0.0	2.0	14.3	2.0	14.3
1	1.0	7.1	5.0	35.7	7.0	50.0
2	1.0	7.1	5.0	35.7	3.0	21.4
3	4.0	28.6	2.0	24.0	2.0	14.3
4	3.0	21.4	0.0	0.0	0.0	0.0
5	3.0	21.4	0.0	0.0	0.0	0.0
6	2.0	14.3	0.0	0.0	0.0	0.0
Total	14.0	100.0	14.0	100.0	14.0	100.0

Table 3. The total time values presented as frequencies and percentages

Chloroform			Eucalyptol			D-Limonene		
Total Time (seconds)	Freq.	Percent (%)	Total Time (seconds)	Freq.	Percent (%)	Total Time (seconds)	Freq.	Percent (%)
156	1.0	7.1	201	1.0	7.1	157	1.0	7.1
301	1.0	7.1	265	1.0	7.1	247	1.0	7.1
305	1.0	7.1	294	1.0	7.1	258	1.0	7.1
363	1.0	7.1	318	1.0	7.1	262	1.0	7.1
372	1.0	7.1	327	1.0	7.1	277	1.0	7.1
428	1.0	7.1	334	1.0	7.1	334	1.0	7.1
429	1.0	7.1	342	1.0	7.1	356	1.0	7.1
439	2.0	14.3	356	1.0	7.1	357	1.0	7.1
449	1.0	7.1	358	1.0	7.1	369	1.0	7.1
508	1.0	7.1	370	1.0	7.1	378	1.0	7.1
556	1.0	7.1	429	1.0	7.1	400	1.0	7.1
591	1.0	7.1	515	1.0	7.1	414	1.0	7.1
871	1.0	7.1	609	1.0	7.1	712	1.0	7.1
			699	1.0	7.1	745	1.0	7.1
	14.0	100.0		14.0	100.0		14.0	100.0

Table 4. Comparisons of the median initial depth, total time and the additional drops of solvent for the various solvents.

Variables	Solvents	Median (50)	Interquartile Range (25-75)	p-value
Initial Depth (mm)	Chloroform	9.00	6.00 - 11.00	0.737
	Eucalyptol	9.00	7.00 - 14.25	
	D-Limonene	8.00	7.00 - 10.00	
Total Time (secs)	Chloroform	434.00	312.00 - 520.00	0.180
	Eucalyptol	349.00	348.50 - 450.50	
	D-Limonene	356.50	261.00 - 403.50	
Additional Drops (numbers)	Chloroform	4.00	3.00 - 5.00	<0.001*
	Eucalyptol	1.50	1.00 - 2.00	
	D-Limonene	1.00	1.00 - 2.00	

* Indicates statistically significant difference using the Independent Kruskal-Wallis test ($p < 0.05$)

Limonene group (1.0), while the most drops of solvent used were by the Chloroform group (4.0).

DISCUSSION

Endodontic retreatment is one of the treatment options for failed root canals, with success rates of between 50% and 90% [34]. Solvents in combination with K-files are the most common method of removing gutta-percha (38.6%) from root canals by Ghanaian dentists, with eucalyptol being the most used solvent (79.5%) [11]. After dental caries, periodontal disease and trauma are the most common reasons for tooth extraction [35,36]. The greater number of maxillary central incisors in this study may be due to the higher incidence of its loss secondary to periodontal disease. In a study on the prevalence of periodontitis by Hewlett et al. [37] in Ghana, almost half of the respondents surveyed (46.7%) had periodontitis; of these, 13.9% had severe periodontitis. A ten-year longitudinal study on the progression of untreated periodontal disease showed that central incisors were lost more often than lateral incisors [38]. The use of solvents in endodontic retreatment decreases working time and minimises the risk of root perforations, canal straightening, or alterations in the original canal shape [7].

This study's results indicate no significant difference ($p = 0.737$) in the initial depth of penetration of the K-file into the gutta-percha. Eucalyptol and D-Limonene are both non-polar solvents, while chloroform, though classified as a polar solvent, has weak non-polar properties [22]. All three solvents are thus able to cause the separation of gutta-percha polymer strands to initiate the softening of the gutta-percha and aid the penetration of the K-file into the gutta-percha. The result from this study is different from the results of a study by Wennberg and Ørstavik [13] conducted in Sweden, where the depth of penetration of a small indentor of a fixed weight and shape was inserted into gutta-percha discs (diameter 10mm, height 8mm) which had been covered with six different test solutions (Eucalyptol, Xylol, Methyl chloroform, Tetrahydrofuran, Methylene chloride and chloroform) at different set times (1,2,5,10,15, and 30 minutes). It was found that the discs with the Eucalyptol solvent had the least depth of penetration as compared to chloroform for all the time intervals. Chloroform had the highest depth of penetration at all time intervals.

The differences in the depth of penetration between the current study and the Wennberg and Ørstavik study might be due to the differences in the methods used [13]. In the Wennberg and Ørstavik study [13], an indenter of a fixed weight and shape was used to penetrate the gutta-percha, and the measurements of the depths of penetration were done at fixed time intervals. The present study sought to simulate an in-vivo clinical scenario where the clinician applied a gentle indeterminate force in the removal of the gutta-percha from the root canals. Several studies have shown that additional drops of solvents were added to the initial drops of solvent left in the created reservoirs. However, the studies did not record or analyse the difference in the number of drops used by the various solvents [9,39,40]. D-Limonene is a non-polar solvent with high amounts of monoterpene hydrocarbons. This makes it able to penetrate the non-polar gutta-percha polymer and separate the strands easily [41]. Because of the ease of penetration and separation of the gutta-percha polymer strands, fewer drops of the solvent are required to remove it from the root canal. Another reason for the least number of drops utilised by D-Limonene might be due to the high content (59.1% to 75.3%) of zinc oxide fillers in gutta-percha [16]. In dentistry, D-Limonene has been used in the dissolution of zinc oxide cemented root-fillings [20,28]. Further research might be needed to prove if this is the case.

The results of a study by Uemura et al. [42] conducted in Japan showed similar results to this study in that a greater volume of Chloroform was needed to clean the canal walls as compared to Eucalyptol and D-Limonene. The increased number of drops of chloroform needed during the procedure could be attributed to its high volatility rate. Because chloroform evaporated quickly, the contact time between the solvent and gutta-percha was reduced. This resulted in an increased number of drops being needed during the procedure. The minimal number of drops of D-limonene and Eucalyptol is an advantage in terms of cost in a clinical setting. Chloroform's high volatility rate could lead to an increased rate of inhalation among dental staff and patients. This is another reason why alternate solvents to chloroform must be investigated. When solvents are used during endodontic retreatment, the surface of the gutta-percha is wet by contact with the solvent. Penetration of the file into the gutta-percha increases the contact area for the action of the solvent [43]. Solvents act by destabilising the covalent bonds between the gutta-percha atoms. An increase in the depth of penetration of the file into the softened gutta-percha allows for a greater contact area of the file with the gutta-percha, which leads to the removal of a greater amount of gutta-percha on the outstroke of filing. This leads to a reduction in the time clinicians use for the retreatment procedure [43].

Results from this study indicate no significant differences ($p = 0.180$) in the total time it took to remove all the gutta-percha from the root canals. Chloroform might have taken the longest time to completely remove gutta-percha because it formed a sticky residue that was more difficult to remove than Eucalyptol and D-Limonene. Chloroform is a polar solvent but has weak non-polar properties [22]. During the solvation process, the gutta-percha polymer chains are surrounded by the chloroform molecules. This causes the gutta-percha to swell and become viscous [34]. The high viscosity/ sticky residue of the resulting gutta-percha is what causes the prolonged time in its removal from the root canal. In a study in Croatia by Karlović et al. [40] in which three solvents - Eucalyptol, Halothane, and Orange Oil, were used in retreatment and the total time for the completion of treatment was recorded, a statistically significant difference was observed in the times for completion of treatment with eucalyptol having a faster time than Halothane and Orange Oil [40]. In this study, though eucalyptol also had the fastest time in removing all gutta-percha from the root canal compared to the other two solvents, there was no significant difference among the solvents. The difference in statistical significance might be due to the volume of solvent deposited in the created reservoirs for each study. In the Karlović study, 0.4 ml of solvent was deposited in the reservoir, while in our study, 0.02 ml (2 drops of 10 µL) was used. The larger volume of solvent used in the Karlović study might have meant there was more solvent in contact with the gutta-percha at the time of initial deposition of the solvent and during penetration of the file into the gutta-percha as a greater surface area would be in contact with the solvent, leading to greater softening of the gutta-percha and more ease in its removal from the canal, and therefore a shorter time for its removal.

This study was conducted to simulate endodontic retreatment in a clinical setting. The amount of force delivered on insertion of the hand file into the softened gutta-percha could not be measured and kept constant for each tooth.

Conclusion

In this study, smaller volumes of D-Limonene produced comparable results as Eucalyptol and Chloroform in the softening and removal of gutta-percha from root canals during re-endodontic treatment. Therefore, D-Limonene can be used as an alternative solvent for removing gutta-percha in endodontic retreatment.

DECLARATION

Ethical consideration

Ethical approval was obtained from the Ethics and Protocol Review Committee of the Korle Bu Teaching Hospital (KBTH-STC 00093/2021). Written permission was obtained from the Clinical Director of the University of Ghana Dental School to use teeth from the School's Tooth Bank.

Consent to publish

All authors agreed on the content of the final paper.

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None

Competing Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Author contributions

GRY was involved in conceptualising the study. AS and AANA participated in the study design. NTA participated in the data analysis, and OTA and KAB interpreted the results. NEA, APC, and HS participated in supervising the study.

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Availability of data

Data is available upon request to the corresponding author.

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