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Effect Of Final Irrigation Materials And Irrigation Techniques On Dental Root Fracture Resistance

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ABSTRACT

Teeth undergoing root canal treatment are at higher fracture risk due to changes in dentin's mechanical properties from irrigation solutions, leading to erosion and reduced fracture resistance. This study evaluates the effects of various final irrigation solutions and techniques on fracture resistance in treated teeth. An experimental study used 24 mandibular premolars, divided into six groups, each treated with one of two irrigation solutions (17% EDTA or 0.2% chitosan nanoparticles) and one of three irrigation techniques (manual, sonic, ultrasonic). Fracture resistance was measured with a Universal Testing Machine, and results analyzed using two-way ANOVA and Post-Hoc LSD tests. Findings indicated both irrigation solution type and technique significantly affected fracture resistance ($p<0.05$). The group treated with Chitosan Nanoparticles using manual agitation showed the highest fracture resistance, while the EDTA Ultrasonic group showed the lowest. These results highlight the importance of selecting irrigation solutions and techniques to enhance fracture resistance in root canal-treated teeth, with chitosan nanoparticles and manual techniques showing the best outcomes.
Keywords: fracture resistance; final irrigation solutions; irrigation techniques; chitosan nanoparticles

Introduction

Trauma to teeth is a condition of injury to a tooth resulting from impact that can lead to tooth fracture [1]. Although the oral cavity region comprises only about 1% of the total body surface area, this area accounts for 5% of all bodily injuries and ranks fifth among the most common acute/chronic diseases and injuries worldwide [2]. The incidence of dental trauma is 1%–3%, and its prevalence remains stable at 20%–30% [3]. No individual is completely free from the risk of experiencing dental trauma, including endodontically treated teeth. Endodontically treated teeth are at 19.9% risk of fracture [4]. This is because root canal treatment causes irreversible changes in the anatomy, chemical, and mechanical properties of the tooth [5]. Root canal treatment is a procedure aimed at eliminating infection in a tooth and preserving the tooth's function in the oral cavity for as long as possible. Teeth that have undergone root canal treatment have a higher risk of fracture due to changes in the mechanical properties of dentin, one of which is caused by the irrigation process [6]. Irrigation solutions are important for removing the smear layer formed during root canal preparation. The gold standard irrigation solution for removing the smear layer is Ethylenediaminetetraacetic acid (EDTA) 17% [7]. The use of EDTA 17% can significantly reduce dentin hardness, which impacts the reduction of tooth fracture resistance [8]. Irrigation techniques are often employed to maximize the effectiveness of irrigation solutions. Some studies have shown that ultrasonic irrigation is more effective at distributing irrigation solutions within the root canal compared to manual and sonic techniques. Therefore, ultrasonic irrigation is effective in removing the smear layer [9]. Nevertheless, ultrasonic tips are made of steel, which has a higher hardness than dentin; these tips can damage the root canal walls and cause scratches on the dentin surface [10].

In contrast, sonic tips have polymer-based tips, making them relatively safe and not cutting into the root canal walls [11]. The dentin walls of the root canal are crucial for determining the fracture resistance of the root.

Currently, there is research on another final irrigation solution in the form of 0.2% chitosan nanoparticles, which is known to be effective in removing the smear layer without causing erosion of the root canal walls, although it is still in the research stage [12]. Therefore, this study aims to evaluate the effect of final irrigation solutions such as EDTA 17% and 0.2% chitosan nanoparticles, agitated using manual, sonic, and ultrasonic irrigation techniques, as well as the interaction between the final irrigation solutions and irrigation techniques on the fracture resistance of root-treated teeth.

This study is expected to provide clinically beneficial solutions for selecting safer and more effective irrigation materials and techniques for the fracture resistance of root-treated teeth. This is very important, considering that fracture resistance is one of the long-term considerations in endodontic treatment, restoration, and function[13].

Methods

This study is an experimental laboratory study with a quantitative approach aimed at evaluating the effect of the combination of final irrigation solutions and irrigation techniques on the fracture resistance of teeth following root canal treatment. The study was conducted at the Integrated Research Laboratory, Faculty of Dentistry, Universitas Gadjah Mada and the Materials Laboratory, Faculty of Mechanical Engineering, Universitas Negeri Yogyakarta over three months, from January to March 2024. This study received approval from the Research Ethics Committee of the Faculty of Dentistry RSGM UGM Prof. Soedomo, Universitas Gadjah Mada with ethics number KE/FKG/UGM/2024/0012, and all research procedures were carried out in accordance with applicable ethical guidelines. A total of 24 extracted human mandibular premolars were used as samples, with inclusion criteria being single-rooted premolars without caries, resorption, or fracture, and with fully closed apices. Each tooth was radiographically confirmed to ensure it had a single, straight root canal. Teeth with caries, cracks, curved canals, post-endodontic treatment, internal resorption, or calcification were excluded from the study [14]. Selected teeth were cleaned of any adhering soft and/or hard tissue, disinfected by immersion in 5.25% sodium hypochlorite solution for 30 minutes, and stored in sterile saline at room temperature throughout the study. Each tooth was transected to leave a 13 mm root segment using a low-speed disc bur with water cooling [14].

After dissection, dentin thickness standardization was determined by measurements from digital microscope images. This procedure was used to obtain roots with similar dentin thickness. Data were analyzed to verify the distribution of dentin thickness, and then embedded in acrylic resin blocks measuring 2 cm × 2 cm × 2 cm with 2 mm of the coronal portion left exposed. After embedding, root canal preparation was performed using the crown-down technique with rotary files (ProTaper Gold, Dentsply) to an apical size of #20. Irrigation during preparation was conducted with 2.5% sodium hypochlorite (NaOCl), using 2 ml each time files were changed. After preparation was complete, teeth were randomly assigned into 6 groups based on the combination of final irrigation solutions (17% EDTA and 0.2% chitosan nanoparticles) and irrigation techniques (manual, sonic, and ultrasonic). Each irrigation solution was used in a volume of 5 ml, left in the canal for 2 minutes, and agitated for 30 seconds according to the specified technique for each group. After final irrigation, teeth were rinsed with saline to remove residual irrigant and dried with paper points.

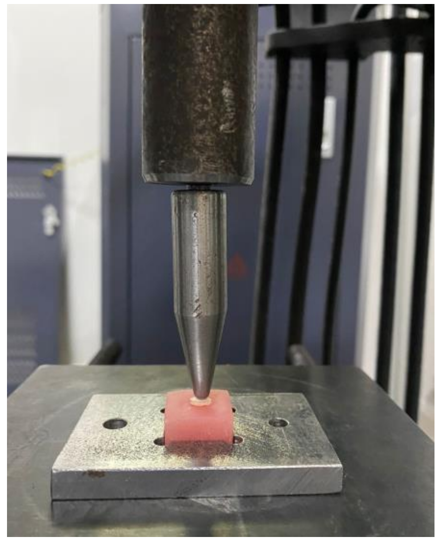

Figure 1. Fracture resistance test using universal testing machine

Fracture resistance of the teeth (Figure 1) was measured using a Universal Testing Machine (UTM), where load was applied vertically at a speed of 1 mm/s until fracture occurred, and the values were recorded in Newtons (N).

Data were analyzed using two-way ANOVA to evaluate the significant effects of irrigation solution and irrigation technique on fracture resistance, followed by Post-Hoc LSD tests to compare between treatment groups. All analyses were performed with SPSS version 29.0.2.0 (20) with a significance level of $p < 0.05$

Results and Discussion

Figure 1. Fracture resistance values of root-treated teeth across final irrigation solution groups and irrigation techniques.

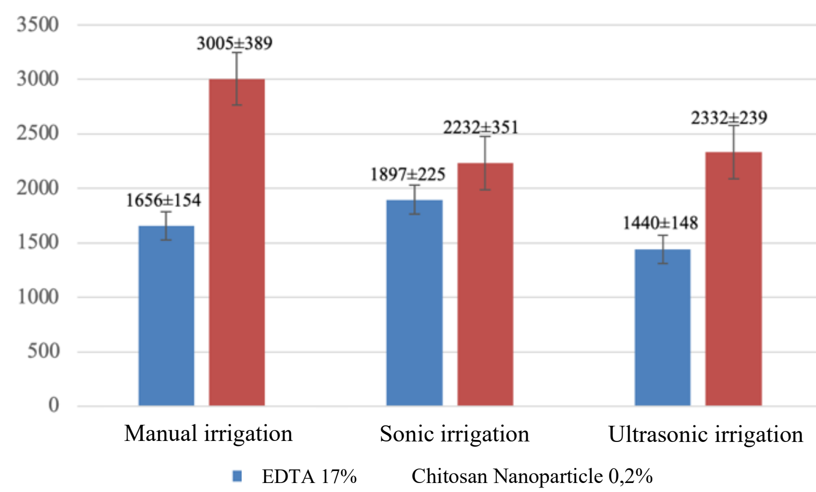

Figure 1 shows that, in general, the groups irrigated with 0.2% chitosan nanoparticle solution produced higher fracture resistance values compared to the groups irrigated with 17% EDTA, whether agitated by manual, sonic, or ultrasonic techniques. The highest fracture resistance value was observed in the 0.2% Chitosan Nanoparticle—Manual group, and the lowest fracture resistance value was in the 17% EDTA—Ultrasonic group.

The fracture resistance data were tested for normality using the Shapiro–Wilk test. The results showed that the data in all treatment groups were normally distributed ($p>0.05$). Next, Levene's Test for homogeneity showed that the variances among groups were homogeneous ($p>0.05$). This confirms that the data meet the basic assumptions for two-way ANOVA.

The two-way ANOVA results indicated that both the type of final irrigant ($p=0.000$), the irrigation technique ($p=0.000$), and their interaction ($p=0.000$) had significant effects on tooth fracture resistance, with all p-values <0.05. This supports the hypothesis that the type of final irrigant, the irrigation technique, and their interaction influence root dentin fracture resistance.

These findings are consistent with Dominguez et al. (2021), who showed that the choice of irrigant significantly affects dentin fracture resistance due to its chemical effects on dentin structure. They also align with Zelthner et al. (2009), who reported that differences in irrigation technique significantly affect root fracture resistance [15].

Sonic and ultrasonic irrigation techniques generate energy through vibration or oscillation that is transmitted to the irrigant within the root canal. These vibrations cause an increase in irrigant temperature, primarily due to acoustic streaming and cavitation. The greater the oscillation, the higher the temperature rise. This temperature rise is further accelerated by friction between the tip and the canal walls. The study also found that temperature can increase more in the apical region, because that location is farther from the outer surface and has thinner canal walls, allowing heat to accumulate. Higher temperatures can affect the reduction of irrigant viscosity [15].

According to Giardino et al. (2021), the lower the viscosity of the irrigant solution, the deeper its penetration into dentinal tubules. Lower viscosity allows the irrigant to flow more easily into narrow spaces such as dentinal tubules. Therefore, the deeper the final irrigant penetrates into the dentinal tubules, the larger the dentin surface area exposed to it, enhancing the chelation effect. This effect causes dentin demineralization by binding and removing calcium ions. Consequently, the resulting demineralization can weaken the dentin structure and potentially reduce root fracture resistance [16]. Post-Hoc LSD tests revealed that the fracture resistance of the 0.2% Chitosan Nanoparticle—Manual group differed significantly from all other groups: 17% EDTA—Manual ($p=0.001$), 17% EDTA—Sonic ($p=0.001$), 17% EDTA—Ultrasonic ($p=0.001$), 0.2% Chitosan Nanoparticle—Sonic ($p=0.008$), and 0.2% Chitosan Nanoparticle—Ultrasonic ($p=0.023$), all $p<0.05$. The 17% EDTA—Manual group differed significantly from the 0.2% Chitosan Nanoparticle—Ultrasonic group ($p=0.02$). The 17% EDTA—Ultrasonic group differed significantly from 0.2% Chitosan Nanoparticle—Manual ($p=0.001$), 0.2% Chitosan Nanoparticle—Sonic ($p=0.006$), and 0.2% Chitosan Nanoparticle—Ultrasonic ($p=0.002$), all $p<0.05$. However, not all group comparisons were significant. The 17% EDTA—Manual group did not differ significantly from 17% EDTA—Sonic ($p=0.792$), 17% EDTA—Ultrasonic ($p=0.875$), or 0.2% Chitosan Nanoparticle—Sonic ($p=0.064$), $p>0.05$. The 17% EDTA—Sonic group did not differ significantly from 17% EDTA—Ultrasonic ($p=0.200$), 0.2% Chitosan Nanoparticle—Sonic ($p=0.504$), or 0.2% Chitosan Nanoparticle—Ultrasonic ($p=0.243$), $p>0.05$. The 0.2% Chitosan Nanoparticle—Sonic group did not differ significantly from 0.2% Chitosan Nanoparticle—Ultrasonic ($p=0.994$), $p>0.05$.

EDTA, known for its strong chelating properties, significantly reduces dentin hardness by removing inorganic minerals from the dentinal tubules [17]. This finding aligns with Dominguez et al. (2018), who reported that EDTA use leads to reduced tooth fracture resistance due to excessive dentin erosion. Although effective at removing the smear layer, EDTA can weaken dentin structure, especially with prolonged use, thereby reducing fracture resistance [8].0.2% Chitosan nanoparticles showed the highest fracture resistance in this study (Figure 2), particularly when combined with manual irrigation. Chitosan nanoparticles, with their smaller particle size and antibacterial properties, can remove the smear layer without causing excessive dentin erosion. This is consistent with Shrestha et al. (2014), who reported that chitosan nanoparticles maintain dentin integrity and enhance mechanical strength. The gentler chelating effect of chitosan compared to EDTA makes it a safer irrigant for preserving tooth fracture resistance [18].

Manual irrigation produced the highest fracture resistance compared to sonic and ultrasonic techniques. Manual irrigation does not generate excessive vibration or significant temperature changes during the irrigation process, reducing the risk of dentin erosion or microcracks. This supports the hypothesis that gentler, more stable techniques, such as manual irrigation, are safer when combined with 0.2% chitosan nanoparticle irrigant.

Sonic irrigation operates at lower frequencies than ultrasonic (around 1–6 kHz), yielding better irrigant distribution than manual irrigation without excessive destructive effects. Although not as effective as manual irrigation at preserving fracture resistance, sonic irrigation still outperformed ultrasonic irrigation. The vibrations in sonic irrigation are sufficient to optimize cleaning without generating damaging temperatures.

Ultrasonic irrigation yielded the lowest fracture resistance (Figure 2). This technique operates at high frequencies (25–30 kHz), causing intense vibrations and cavitation in the irrigant. Ultrasonic vibrations increase irrigant temperature, reducing its viscosity and accelerating dentin erosion. While effective at canal cleaning, the resulting heat and mechanical stress can induce microcracks in dentin, leading to reduced fracture resistance.

The vibrations from ultrasonic irrigation not only enhance irrigant distribution but also raise canal temperature. This temperature rise lowers irrigant viscosity, allowing deeper penetration into dentinal tubules. However, the combination of reduced viscosity and cavitation can exacerbate dentin erosion. Cavitation generates strong microforces that can damage canal walls, causing microcracks that diminish tooth fracture resistance. Therefore, although ultrasonic irrigation effectively cleans the canal, its side effects—dentin erosion from high temperature, cavitation, and low viscosity—must be considered.

Some non-significant findings may be due to the differences in the effects of irrigant type and technique not being large enough to produce statistically distinct outcomes. For EDTA, its strong erosive effect may overshadow any influence of irrigation technique on fracture resistance. This study has limitations, such as variation in tubule orientation affecting dentin's anisotropic properties and the presence of air bubbles in the apical third that cannot be visually verified. Root dentin's mechanical properties are influenced by the orientation of dentinal tubules and collagen fibers. Dentin is anisotropic, exhibiting lowest strength when forces are parallel to the tubules and highest at a 90° angle. Scanning Electron Microscope (SEM) analysis shows that dentin microstructure influences fracture patterns, confirming the role of tubule orientation in dentin's mechanical properties, particularly regarding collagen matrix disruption [19].

Another challenge is the possible presence of air bubbles trapped in the apical third of the canal. These bubbles, known as the vapour lock phenomenon, occur when air is trapped at the canal apex, preventing optimal irrigant penetration. Trapped air can create a physical barrier that impedes fluid flow, especially in the narrow apical third. Peeters et al. (2022) explained that these trapped air bubbles cannot be visually detected due to the limitations of detection tools, making it difficult to ascertain the extent of the apical area left untouched by the irrigant [20].

This study is also limited by the inability to visually verify trapped air. Radiographic or other imaging methods may be insufficient to clearly detect small air bubbles within the canal, particularly in very narrow regions like the apical third. This poses a methodological challenge in measuring the impact of vapour lock on cleaning and disinfection outcomes[20].

Conclusion

This study demonstrates that both the type of final irrigant and the irrigation technique have significant effects on the fracture resistance of teeth that have undergone root canal treatment. The use of 0.2% chitosan nanoparticles with manual irrigation produced the highest fracture resistance, whereas the combination of 17% EDTA with ultrasonic irrigation produced the lowest fracture resistance (Figure 2). Irrigants with strong chelating properties, such as EDTA, tend to cause more significant dentin erosion, thereby reducing tooth fracture resistance. In contrast, 0.2% chitosan nanoparticles provide better protection of the dentin structure without causing excessive erosion. Manual irrigation proved safer for preserving fracture resistance compared to sonic and ultrasonic techniques, which can induce erosion due to vibration, temperature increases, and cavitation.

The findings of this study provide scientific justification that selecting the appropriate irrigant and technique is crucial in clinical practice to minimize dentin damage during root canal treatment. Further research is needed to explore additional final irrigants and irrigation techniques that can improve clinical outcomes without causing mechanical damage to teeth, taking into account other factors such as vapour lock and variations in dentinal tubule orientation that affect the effectiveness of root canal cleaning.

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