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Effect of Intermediate Irrigation on Temperature Rise during Broken NiTi File Removal Using Ultrasonic Device

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Abstract: Endodontic preparation with ultrasonic instruments can lead to temperature rise (TR) on the external root surface (ERF), which may damage the periodontium. The aim was to measure the TR due to the ultrasonic preparation applied at different energy levels and durations during the removal of broken endodontic instrument from the root canal. Thirty-five maxillary central incisors were decoronated and 4 mm of NiTi instruments were fractured 5 mm from the most coronal part of the root. The roots were divided into seven groups according to the preparation mode (endodontic-E5, periodontal-P3) and preparation duration (30 s, 45 s, 60 s). Ultrasonic preparation was performed in periods consisting of four preparation phases with intermediate irrigations and drying. During all preparations, the TR was recorded on ERF using a K-type thermocouple. The results demonstrated that the TR measured at the end of the preparation period was higher than at baseline in all groups ($p < 0.001$). The largest TR (8.0 ± 0.5 °C) occurred at high energy level (P3) with 60 s preparation duration ($p < 0.001$). The TR measured after rinsing was significantly lower than before rinsing ($p < 0.001$). In conclusion, rinsing between ultrasonic preparation phases can reduce the TR, which might be potentially harmful using high-energy exceeding 60 s.

Keywords: endodontic preparation; broken NiTi file; ultrasonic device; thermal effect

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1. Introduction

Ultrasonic instruments, common and popular in many fields of dentistry, are nowadays an integral part of endodontic treatments [1].

Ultrasonic instruments have three main applications in endodontics: on the one hand, they help the operator to activate fluids in the root canal (e.g., sodium hypochlorite) to facilitate the removal of bacterial flora and debris; secondly, they can be used for tooth preparation; and thirdly, ultrasonic vibration can be used to remove intracanal posts and broken instruments [1].

Obstructions, such as broken instruments, are factors that make root canal treatment more difficult and affect the outcome of the procedure [2]. When instrument fracture occurs, several treatment strategies can be used: trying to remove the instrument, attempting to bypass the instrument, or sealing the root segment occupied by the broken instrument [3]. Studies using ultrasonic instrumentation to remove broken segments have reported favorable results [4], with success rates of 54.4% to 93.3%. Ultrasonic file removal methods are mostly based on the Ruddle technique or a variation of it [5]. A platform is created using a Gates-Glidden drill (2–4) prior to instrument use. The Gates-Glidden drill is modified by cutting through the maximum cross-sectional diameter perpendicular to its longitudinal axis. The ultrasonic instrument is activated at a lower power setting in the root canal, and then the fractured instrument is circulated counterclockwise or clockwise, depending on the direction of the instrument edges. The vibration transmitted by this action often causes the broken instrument fragment to loosen and then to "pop out" of the root canal [5]. Removal of the separated instrument is beneficial in terms of treatment prognosis because it can prevent full disinfection and hermetic sealing of the root canal [6]. To date, there is no standard procedure for the safe removal of broken instruments, although various techniques have been proposed [3]. These methods have met limited success, while often causing significant damage to the remaining root [7,8].

The introduction of the nickel–titanium (NiTi) alloy in endodontics has allowed the fabrication of a more flexible and resistant instrument [9]. Compared to previously applied hand files, the use of this alloy has allowed for standardized and reliable root canal preparation [10].

Despite the advantages of nickel–titanium files [11], the risk of instrument breakage remains an unresolved problem for practitioners, mainly because fracture can occur without any significant distortion of the instrument [12].

Previous studies have shown that interventions with ultrasonic instruments, such as the removal of a fragment from the root canal, can cause a temperature rise on the external root surface [13–16]. Heat within the root canal can be generated as a result of removing dentin around the fractured segment by specially designed tips activated by different energy levels of ultrasonic vibration. It was demonstrated that bone removal around the inferior alveolar nerve canal with an ultrasonic device can increase the canal temperature bywith 9 °C [16]. Despite the low thermal conductivity of dentin [17], it can transmit heat to the external surface of the root and tooth supporting tissues, leading to damage of the periodontium. A 10 °C temperature rise for 60 s has been reported to result in reversible tissue damage [18,19]. Studies, conducted to investigate the temperature rise on the external root surface during intracanal fractured endodontic files with ultrasonic devices, demonstrated a 4.2 °C–11 °C increase, depending on the unit, power setting, and duration used [14,15,20]. Additionally, the type of fractured instrument has also an effect on the heat amount generated during removal. Higher temperature rise was found with a fractured NiTi instrument, compared to a stainless steel fragment [20]. Furthermore, heat can also be generated as a result of the friction between Gates-Glidden drills and root canal walls while the staging platform is being prepared [21]. Heat-induced bone tissue injury may lead to tooth extraction in a real clinical situation [22]. In order to decrease the risk of thermal injury, water cooling is recommended during the ultrasonic preparation [23]. Although water cooling provides an acceptable result for reducing the thermal effect, it is worth looking for other solutions due to the disadvantage of limiting visual control. To the best of our knowledge, none of the published studies examined the beneficial effect of intermediate root canal irrigation between preparation phases.

The aim of the present study is to investigate the temperature changes on the external surface of the root due to piezoelectric ultrasonic preparation during the removal of a fractured NiTi endodontic instrument.

The following null hypotheses were established: (1) The first hypothesis assumed that the preparation of the staging platform using Gates-Glidden drills would not increase the temperature on the external root surface. (2) The second hypothesis presumed that there is no difference in the temperature rise caused by the used preparation settings when the ultrasonic file is activated and the fractured NiTi rotary file. (3) Thirdly, it was hypothesized that the rinsing between preparation sequences would not influence the temperature change. (4) Finally, the fourth hypothesis assumed that the thermo-conductive medium surrounding the root and the illumination by the microscope light would not influence the temperature change on the external root surface.

2. Materials and Methods

2.1. Teeth Collection

Thirty-five human upper central incisors extracted for periodontal reasons were used in the study. After extraction, the teeth were cleaned with a manual scaler and disinfected in a 2% sodium hypochlorite solution for one day and stored in distilled water until they were used (for a maximum of three months). The crowns of the teeth were removed with a needle diamond bur (No.859.314.014, Komet, Besigheim, Germany), leaving a 10 mm long root. Only roots free of pathological hard tissue changes were included. The length and the mesiodistal diameter at the coronal plane of each root were verified using a screw thread micrometer with 0.001 mm accuracy (Mitutoyo, Tokyo, Japan).

Based on the measurement, the teeth were divided into three categories such that each category contained approximately an equal number of teeth. Category 1 included the smallest teeth with a mesiodistal diameter of less than 5 mm (12 teeth), teeth with a mesiodistal diameter between 5 and 6 mm (11 teeth) were classified into category 2, and teeth with a mesiodistal diameter of more than 6 mm (12 teeth) were placed in category 3. Roots were divided into seven experimental groups (five each) in such a way that no statistically significant differences (one-way ANOVA, $p = 1.00$) between the mesiodistal cross-section diameter means (overall mean diameter 5.6) were found.

2.2. Sample Preparation and Temperature Measurement

The root canals of the teeth were made accessible to the mechanical root canal instrumentation by using a size 10 K-file (Maillefer, Ecublens, Switzerland). After manual instrumentation, distilled water was injected into the root canals with a syringe fitted with an endodontic cannula (25G) to remove debris.

The 4 mm tip of nickel–titanium Reciproc blue (VDW, Munich, Germany) size 25 (R25) files were fractured 5 mm from the most coronal end of the root. To facilitate the manual breakage and achieve a standard length of the fragment, a thin notch was made 4 mm from the tip of the file using a needle diamond bur (No.6889.314.010, Komet, Besigheim, Germany) with a high-speed handpiece. Figure 1 shows the steps of sample preparation for temperature measurements.

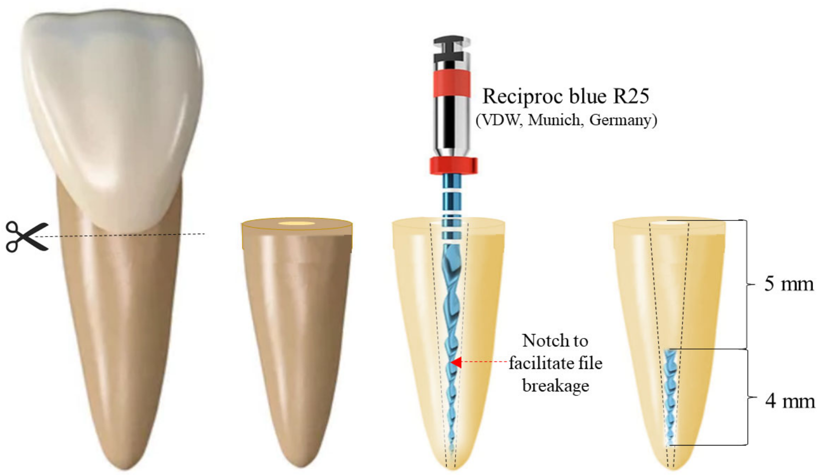

Figure 1. Schematic figure of the sample preparation for temperature measurements.

Temperature measurements were recorded using a Testo 845 (Testo, Lenzkirch, Germany) infrared thermometer attached to a 0.5 mm diameter K-type (NiCr-Ni) thermocouple with a resolution of 0.1 °C and an accuracy of ±0.75 °C in contact with the root surface. The thermocouple was bonded to the disto-external surface of the root at the level of the most coronal part of the broken fragment using Filtek Ultimate Flow (3M ESPE, St. Paul, MN, USA) shade A3 (3M ESPE, St. Paul, MN, USA) flowable resin-based composite. The roots bonded with the thermocouple were fixed in a ProTrain endodontic training kit platform size 2 holder (Simit Dental, Mantova, Italy). Conductive gel (room temperature, 25 ± 1 °C) of the ProTrain kit was used as a heat-conducting medium around the roots.

Gates-Glidden (GG) drills (no. 2, 3, 4, corresponding to the root canal sizes of the three categories) were used to prepare the staging platform coronal to the fractured fragment. GG drills were changed after each five teeth considering the wear of the instrument. According to our pilot study, 30 s preparation time at 2000 revolution per minute (rpm) with each GG was sufficient to prepare the root canal coronal to the fragment. The first GG was used to ensure that the ultrasonic instrument could properly access the broken nickel–titanium instrument. The second GG was modified by grinding the drill perpendicular to its long axis at its maximum cross-sectional diameter to create a flat tip ensuring staging platform preparation coronal to the fractured segment.

During the preparation with GGs, the temperature changes were recorded. After preparation, the root canal was rinsed with 1 mL of 25 °C ± 1 °C distilled water. The canal was then dried using two paper points corresponding to the size of the canal.

Ultrasonic preparation was performed using a piezoelectric multifunction dental scaler, a Woodpecker UDS-E LED (Woodpecker, Guilin, China) ultrasonic device with a size 25 stainless steel ultrasonic U-file captured in a 120° E1 clamping tip (endochuck) (EMS, Herrliberg, Switzerland). The ultrasonic preparation of a root canal was followed by rinsing and drying, which was repeated four times per root canal, giving a period of the preparation (Figure 2). Based on the duration of ultrasonic preparation, test groups were created with preparation times of 30, 45, and 60 s (Table 1). The duration of rinsing and drying was set to 30 s. For the exact timing of the experiments, the Interval Timer program for mobile phones (Dreamspark, Taipei, Taiwan) was used, which allowed to set several time intervals per signal. Temperature changes were recorded continuously during each preparation and rinsing–drying period. Temperature at the baseline and at the end of each period was subtracted from the next record to calculate the temperature rise or drop between the periods. There was no goal of removing the fractured segment.

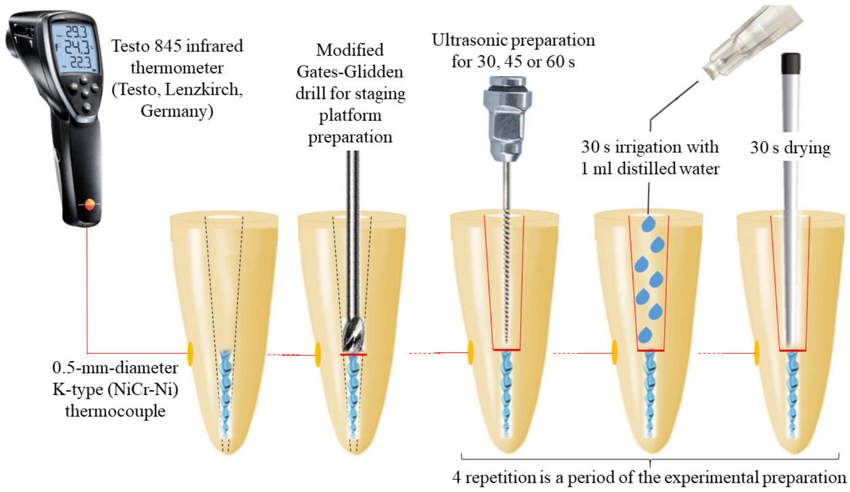

Figure 2. Schematic figure of the steps of the experimental preparation.

Table 1. Study groups.

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7 *
Preparation mode	E5	E5	E5	P3	P3	P3	P3
Preparation time	30 s	45 s	60 s	30 s	45 s	60 s	60 s

Abbreviations: E5, endodontic mode—power level 5; P3, periodontal mode—power level 3 (* Group 7—the roots are not surrounded by thermo-conductive medium).

2.3. Experimental Groups

Seven study groups (n = 5 each) were established according to the preparation mode and time (Table 1). In groups 1, 2, and 3, the ultrasonic device was used in endodontic function at a power setting of 5 (P5), and the preparation time was 30 s, 45 s, and 60 s, respectively. In groups 4, 5, and 6, the device was used in periodontal function mode at a power setting of 3 (P3), while the preparation time was set at 30 s, 45 s, and 60 s, respectively. The maximum power level of the ultrasonic device was 10 units. Group 7 served as a control group to determine the extent of temperature rise by the microscope light and to study the rate of temperature changes on the external root surface without the heat dissipation medium around the roots. The microscope (Leica M320, Leica, Wetzlar, Germany) LED light was set to the same (maximum) intensity as used for all preparations. The microscope light illuminated the roots for 7 min and 30 s.

2.4. Statistical Analysis

SPSS Statistics 26.0 (SPSS, Chicago, IL, USA) software was used to perform statistical analyses. To test the normality of the distribution of the data, the Kolmogorov–Smirnov test was applied. To verify the hypothesized differences, independent and paired-sample *t*-tests were used, where the acceptability of the results was tested using the Cohen's d effect size index. The Cohen's d effect size is small below 0.2, medium from 0.3 to 0.7, and large above 0.8 [24]. The differences in temperature changes were compared using one-way and mixed Analysis of Variance (ANOVA). The acceptability of the results was tested using the partial η^2 (η^2_p) effect size index, which indicates a weak difference in the range of 0.01–0.06, a moderate difference in the range of 0.06–0.14, and a strong difference above 0.14 [24]. Tukey's post hoc adjustment was used for multiple comparisons for all the ANOVA models. The statistical significance was set at $p < 0.05$.

3. Results

Comparison between the baseline temperature (M = 27.4 °C; S.D. = 1.92 °C) and the temperature rise caused by the GG drills (M = 29.5 °C; S.D. = 1.76 °C) resulted in significant difference with a large effect size [t(29) = 5.59; $p < 0.001$; Cohen's d = 1.02], however, there was no significant difference [t(29) = 0.538; $p = 0.595$] observed between the preparations with the first and the second modified GG. The results of the measurements during ultrasonic preparation showed that temperature rise was generated in every preparation period, since the temperature at the end of the preparation was always higher than at the baseline regardless of the preparation settings. The highest average temperature rise was achieved using P3 mode at a 60 s time interval.

The temperature measured at baseline [Mean (M) = 27.5 °C; Standard Deviation (S.D.) = 1.45 °C] was significantly lower than the temperature measured at the end (M = 30.9 °C; S.D. = 4.77 °C) of the preparation period with medium effect size [t(34) = 4.22; $p < 0.001$; Cohen's d = 0.71]. The first preparation showed the highest temperature increase, while the subsequent preparations within a period showed lower temperature rise. This observation was tested using one-way ANOVA, which showed a significant difference [F(3,102) = 6.48; $p < 0.001$; $\eta^2_p = 0.16$]in the value of temperature rise among some of the preparations (Figure 3).

Differences between temperature rise within one period using paired-sample *t*-tests were as follows: preparations 1 vs. 2 [t(34) = 3.58; $p = 0.006$] and preparation 1 vs. preparations 3 and 4 [t(34) = 3.64; $p = 0.005$)] were significant, while there were no differences in preparation 2 vs. 3 [t(34) = 0.81; $p = 0.848$], preparation 2 vs. 4 [t(34) = 0.91; $p = 0.804$], and preparation 3 vs. 4 [t(34) = 0.01; $p = 1.000$]. When comparing the temperature at the end of each preparation to the temperature at the end of the subsequent irrigation, it was confirmed that rinsing with a 24 °C solution resulted in significant decrease of temperature measured at the external root surface with a large effect size (Figure 3).

Preparation mode was found to have a significant effect on temperature change with a large effect size [F(1,24) = 219.7; $p < 0.001$; $\eta^2_p = 0.90$]. The preparation with the P3 mode was associated with a greater temperature increase than preparation with the E5 mode (Figure 4). Statistically significant differences with a large effect size were also observed based on the duration of the preparation [F(2,24) = 25.8; $p < 0.001$; $\eta^2_p = 0.68$]. The differences between the tested durations using mixed ANOVA were as follows: 30 s vs. 45 s [t(24) = 3.03; $p = 0.015$; Cohen's d = 1.36), 30 s vs. 60 s [t(24) = 7.15; $p < 0.001$; Cohen's d = 3.20], and 45 s vs. 60 s [t(24) = 4.12; $p = 0.001$; Cohen's d = 1.84]. Furthermore, the interaction of the variables, such as preparation mode and duration, also showed a significant effect [F(2,24) = 24.7; $p < 0.001$; $\eta^2 p = 0.67$] on the temperature rise.

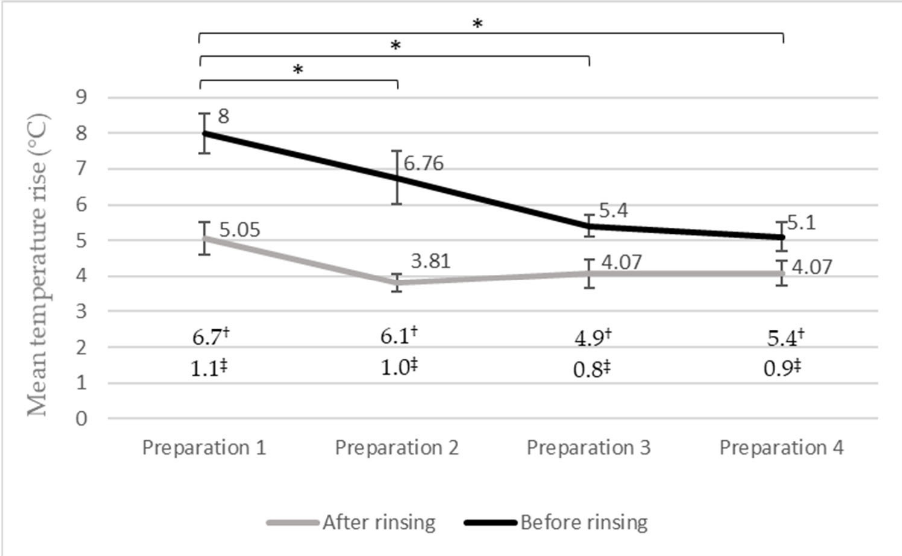

Figure 3. Averaged temperature rise of a period of preparation before and after rinsing (* mark demonstrates statistically significant difference between preparations according to the paired-sample *t*-test. † indicates t-values with $p < 0.001$ and ‡ indicates Cohen's d effect size values).

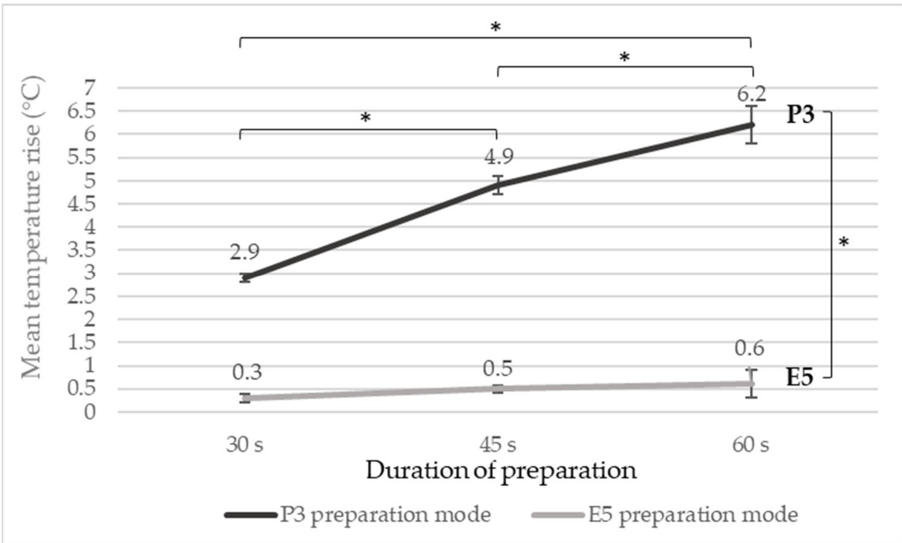

Figure 4. Averaged temperature rise induced by preparation modes of E5 (endodontic mode at a power level of 5) and P3 (periodontal mode of the ultrasonic device at a power level of 3) of the ultrasonic device in relation to preparation time. (* mark demonstrates statistically significant difference between preparations according to the mixed ANOVA model).

To test the fourth hypothesis, Group 6 and Group 7 (control group)—set to the same parameters, except the thermal-conductive medium—were compared using independent-samples *t*-tests, which revealed that the temperature increase was significantly lower with a large effect size [t(8) = −16.4; $p < 0.001$; Cohen's d = −10.4] in the preparation with the conductive medium.

Additionally, the results of the paired-sample *t*-test showed that the light of the microscope had no significant effect [t(4) = 2.45; $p = 0.07$] on the temperature changes during removal of a fractured segment.

4. Discussion

When removing broken instruments from the root canal, an important goal is to minimize the associated complications, such as root perforation, excessive tooth loss, and damage to the periodontium caused by excessive temperature rise on the external root surface [25].

Our null hypotheses assumed that the temperature on the external root surface would not change during the removal of a fractured Reciproc blue file using Gates-Glidden drills and an ultrasonic device applied at different setting parameters. According to the results, the first and the second hypotheses were rejected, since both the preparation with Gates-Glidden drills and the ultrasonic preparation set at different parameters increased the temperature on the root surface. A modified ultrasonic technique [26] ensures a so-called staging platform providing sufficient space around the fragment to allow the use of an ultrasonic tip [27]. A concern with this technique is the heat generated by the Gates-Glidden burs in the root canal, which is transferred to the external root surface. This may damage the periodontal ligaments and the alveolar bone, resulting in minor injuries, such as hyperemia and fat cell deposition, or more significant damage, including ankylosis, bone resorption, and bone necrosis [18,19,28]. Madarati and Watts found a temperature increase of 2.7 °C using GG at 2000 rpm [21], which is in line with our results when using the first GG. However, during the platform preparation with the modified GG, the average temperature increase was only 2.1 °C. These values cannot be considered harmful to the periodontium [18,19]. Ultrasonic tips have been recommended as the most common instruments to remove broken files [3,21] after the platform preparation. The ultrasonic tip trephines the dentin around the fragment, and, furthermore, the vibration against the broken segment finally can loosen it. Although this technique was reported to have a success rate of 70.5%, some complications can occur, including heat generation [25,29].

According to our results, the temperature rise during ultrasonic fragment removal was dependent on the setting parameters of the unit, the time interval of the manipulation, and the irrigation applied between the preparation phases. The measured temperature values in the present study are comparable with the findings of Madarati et al. [14], who described a 0.6–11.2 °C temperature rise, which was also dependent on the power setting, application time interval, and the temperature recording site of the root. In general, strong influence of the setting parameters was detected, as previously published [14,15]. In our study, endodontic function at a power level of 5 (E5) and periodontal function at a power level of 3 (P3) were selected to represent different frequencies and amplitudes of vibration. The frequency of the ultrasonic device used in this study was 28 kHz ± 3 kHz and the amplitude was <200 μm. According to the manufacturer's, these parameters were determined based on dental experiences. P3 mode represented a higher frequency with a higher vibration amplitude compared to E5 mode. Although using the combination of P3 mode and U-file caused a higher temperature rise, it did not reach the potentially harmful threshold of 10 °C. In addition, the vibration was so powerful, leading to damage or even fracture of the U-file during the experimental preparation. The endochuck adaptor used to capture the U-file increased the length of the tip, thus increasing the risk for the working frequency to change. This may shift the resonance frequency outside of the working range of the piezoelectric crystal [30]. E5 mode represented lower frequency and amplitude of the vibration, leading to a much lower temperature rise. At this lower energy level, the operating time interval had no strong effect on the temperature rise, however, the impact of the manipulation time on temperature rise was significant using P3 mode. As the duration of the preparation increased, the temperature passing through the dentin also increased. The highest mean temperature was recorded in P3 mode at a 60 s time interval. This is in accordance with the readings of other investigation, where significant temperature increase was registered at extended manipulation time [13,14,20]. Therefore, it is worth mentioning that it is beneficial to interrupt the preparation sequence during ultrasonic activation in order to allow sufficient time for the dentin to cool down [20]. In addition to the setting parameters of the devices, the material of the fragment also affects the temperature change during removal. Madarati found that the removal of a NiTi file compared to a stainless steel file induced higher temperature rise during removal [20]. In conclusion, it was recommended that lower power settings and shorter application times be applied when using ultrasonics to remove NiTi fragments compared to stainless steel ones [20]. In our experimental model, a Reciproc blue heat-treated NiTi file was broken into the root canal. Thanks to the innovative thermo-mechanical treatment, the structure modification resulted in a flexible instrument resistant to cyclic fatigue [31]. The temperature rise in our study was lower than what was presented by Madarati [20].

Since our results demonstrated a temperature-reducing effect of rinsing after each preparation phase, the third hypothesis was rejected. To the best of our knowledge, there are no studies investigating the combination of ultrasonic preparation and intermediate irrigation for removal of a broken instrument. Activating the ultrasonic tips without any coolant was considered to simulate the recommended clinical conditions and to present the worst-case scenario of heat generation [5,13,14]. To overcome the problem regarding the heat development induced by the vibration energy, a specifically designed ultrasonic unit and tip with air-spray function has been developed and is reported to effectively reduce temperature even with an application time of 120 s [15]. Another possible way to reduce the temperature without limiting the visual control is to use a rinsing solution between preparation phases. Even if the temperature exceeds the potentially harmful threshold, irrigation with a room-temperature or colder solution can facilitate the temperature decrease after a phase of ultrasonic preparation. This in vitro experimental result may be of importance for clinicians, as it suggests a similar cooling effect of agents used in the clinic for root canal disinfection and debris removal (e.g., sodium hypochlorite). This aspect may be important to protect the periodontium. As a future direction, it would be worthwhile to investigate the cooling effect of irrigation solutions at different temperatures, including refrigerated ones.

Due to the favorable morphological characteristics, upper central incisors were used in this study to test the temperature increase. The dentin thickness around root canals of different teeth is dissimilar [32]. For this reason, the results of our measurements cannot be extrapolated to all teeth, since the present study used extracted upper first incisors with relatively big cross-sectional diameters. By increasing dentin thickness, increasing heat insulating effect but, at the same time, heat-storing capacity was also demonstrated [17]. In light of the fact that dentin heat-storing capacity is significant, the manipulation time is even more important. Prolonged (60 s) thermal stress (10 °C) was proved to induce irreversible changes in the bone [18].

Based on the results obtained in our study, the fourth hypothesis should be partially rejected, which partly assumed that the thermal conductivity of the medium surrounding the root has no influence on the temperature change. A thermal conducting medium, ProTrain gel, was used to simulate the surrounding tissues of the root, which showed a significant thermal reducing effect compared to the control group without the gel. As a result of thermal stimuli, the increased perfusion rate and heat dissipating effect of the periodontal blood circulation play important roles in heat conduction and protection against the rise of temperature on the external root surface and at the adjoining alveolar bone [33]. Our results demonstrated a significant temperature increase at the end of the fourth preparation phase in the control group (without medium), and the following rinsing was not able to reduce the temperature below the potentially harmful threshold. Although several thermal conductive mediums, such as silicone impression material [14,15], alginate impression material [13], ultrasound, or echo-transmission gel [34], were used in other studies, none of them were able to account for all the mechanisms by which heat is dissipated in vivo.

The second part of the fourth hypothesis was accepted since the released heat of the microscope light negligibly increased the temperature of the root. Adequate vision, illumination, and magnification are crucial in endodontic procedures, and the success rate of removing or bypassing fractured instruments doubles when the fragment is visible under the microscope [29]. Although the fragment removal time can exceed 45–60 min, during which time the light of the microscope continuously illuminates the tooth, the distance between the light source and the tooth is probably enough to decrease the heat energy released from the light [35].

5. Conclusions

In conclusion, when an ultrasonic U-file is used for removal of a separated Reciproc blue edodontic NiTi file, the temperature rise on the external root surface was found to be a function of power setting, application time, and irrigation between the preparation phases. Although the mean temperature did not exceed the potentially harmful threshold, higher power settings of the ultrasonic unit and extended manipulation time should be avoided. To facilitate the temperature decrease, interruption of ultrasonic preparation with rinsing is recommended.

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Institutional Review Board Statement: All the investigations were performed in accordance with the principles of the Declaration of Helsinki. Ethical approval was granted by the Regional Research Ethical Committee of University of Pécs (approval number: PTE/5629) to use the extracted teeth for research purposes.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ansar, A.; Shetty, K.H. Uses of ultrasonics in endodontics—A review. *Int. J. Adv. Res.* **2017**, *6*, 1448–1459. [CrossRef]
2. Gulabivala, K.; Ng, Y.L. Factors that affect the outcomes of root canal treatment and retreatment-A reframing of the principles. *Int. Endod. J.* **2023**, *56*, 82–115. [CrossRef]
3. Terauchi, Y.; Ali, W.T.; Abielhassan, M.M. Present status and future directions: Removal of fractured instruments. *Int. Endod. J.* **2022**, *55*, 685–709. [CrossRef]
4. Faus-Matoses, V.; Burgos Ibáñez, E.; Faus-Llácer, V.; Ruiz-Sánchez, C.; Zubizarreta-Macho, Á.; Faus-Matoses, I. Comparative analysis of ease of removal of fractured NiTi endodontic rotary files from the root canal system-An in vitro study. *Int. J. Environ. Res. Public Health* **2022**, *19*, 718. [CrossRef]
5. Ruddle, C.J. Nonsurgical retreatment. *J. Endod.* **2004**, *30*, 827–845. [CrossRef]
6. Vouzara, T.; el Chares, M.; Lyroudia, K. Separated Instrument in Endodontics: Frequency, Treatment and Prognosis. *Balk. J. Dent. Med.* **2018**, *22*, 123–132. [CrossRef]
7. Abdeen, M.A.; Plotino, G.; Hassanien, E.E.; Turky, M. Evaluation of dentine structure loss after separated file retrieval by three different techniques: An ex-vivo study. *Eur. Endod. J.* **2023**, *8*, 225–230. [CrossRef]
8. Garg, H.; Grewal, M.S. Cone-beam computed tomography volumetric analysis and comparison of dentin structure loss after retrieval of separated instrument by using ultrasonic EMS and ProUltra tips. *J. Endod.* **2016**, *42*, 1693–1698. [CrossRef]
9. Coelho, M.S.; Rios, M.A.; Bueno, C.E.D.S. Separation of nickel-titanium rotary and reciprocating instruments: A mini-review of clinical studies. *Open Dent. J.* **2018**, *12*, 864–872. [CrossRef]
10. Del Fabbro, M.; Afrashtehfar, K.I.; Corbella, S.; El-Kabbaney, A.; Perondi, I.; Taschieri, S. In vivo and in vitro effectiveness of rotary nickel-titanium vs manual stainless steel instruments for root canal therapy: Systematic review and meta-analysis. *J. Evid. Based Dent. Pract.* **2018**, *18*, 59–69. [CrossRef] [PubMed]

11. Tabassum, S.; Zafar, K.; Umer, F. Nickel-Titanium rotary file systems: What's new? *Eur. Endod. J.* **2019**, *4*, 111–117. [CrossRef]
12. Madarati, A.A. Factors influencing incidents of complications while using nickel-titanium rotary instruments for root canal treatment. *BMC Oral Health* **2019**, *19*, 241. [CrossRef]
13. Hashem, A.A. Ultrasonic vibration: Temperature rise on external root surface during broken instrument removal. *J. Endod.* **2007**, *33*, 1070–1073. [CrossRef]
14. Madarati, A.A.; Qualtrough, A.J.; Watts, D.C. Factors affecting temperature rise on the external root surface during ultrasonic retrieval of intracanal arated files. *J. Endod.* **2008**, *34*, 1089–1092. [CrossRef]
15. Madarati, A.A.; Qualtrough, A.J.; Watts, D.C. Efficiency of a newly designed ultrasonic unit and tips in reducing temperature rise on root surface during the removal of fractured files. *J. Endod.* **2009**, *35*, 896–899. [CrossRef]
16. Szalma, J.; Vajta, L.; Lempel, E.; Tóth, Á.; Jeges, S.; Olasz, L. Intracanal temperature changes during bone preparations close to and penetrating the inferior alveolar canal: Drills versus piezosurgery. *J. Craniomaxillofac. Surg.* **2017**, *45*, 1622–1631. [CrossRef]
17. Kincses, D.; Jordáki, D.; Szebeni, D.; Kunsági-Máté, S.; Szalma, J.; Lempel, E. Effect of ceramic and dentin thicknesses and type of resin-based luting agents on intrapulpal temperature changes during luting of ceramic inlays. *Int. J. Mol. Sci.* **2023**, *24*, 5466. [CrossRef]
18. Eriksson, A.R.; Albrektsson, T. Temperature threshold levels for heat-induced bone tissue injury: A vital-microscopic study in the rabbit. *J. Prosthet. Dent.* **1983**, *50*, 101–107. [CrossRef]
19. Eriksson, A.R.; Albrektsson, T.; Albrektsson, B. Heat caused by drilling cortical bone. Temperature measured in vivo in patients and animals. *Acta Orthop. Scand.* **1984**, *55*, 629–631. [CrossRef]
20. Madarati, A.A. Temperature rise on the surface of NiTi and stainless steel fractured instruments during ultrasonic removal. *Int. Endod. J.* **2015**, *48*, 872–877. [CrossRef]
21. Madarati, A.A.; Watts, D.C. Temperature rise on the external root surface during removal of endodontic fractured instruments. *Clin. Oral Investig.* **2013**, *18*, 1135–1140. [CrossRef]
22. Gluskin, A.H.; Ruddle, C.J.; Zinman, E.J. Thermal injury through intraradicular heat transfer using ultrasonic devices: Precautions and practical preventive strategies. *J. Am. Dent. Assoc.* **2005**, *136*, 1286–1293. [CrossRef]
23. Jadhav, S.B.; Pandit, V.; Gaikwad, A.; Sharma, A. Evaluation of temperature rise on the external surface of root during ultrasonic retrieval of fractured NiTi file from the canal. *Int. J. Curr. Med. Pharm. Res.* **2018**, *4*, 3562–3568.
24. Ferguson, C.J. An effect size primer: A guide for clinicians and researchers. *Prof. Psy. Res. Pract.* **2009**, *40*, 532–538. [CrossRef]
25. Kwon, S.J.; Park, Y.J.; Jun, S.H.; Ahn, J.S.; Lee, I.B.; Cho, B.H.; Son, H.H.; Seo, D.G. Thermal irritation of teeth during dental treatment procedures. *Restor. Dent. Endod.* **2013**, *38*, 105–112. [CrossRef]
26. Ruddle, C. Microendodontics. Eliminating intracanal obstructions. *Dent. Today* **1996**, *15*, 44–46.
27. Madarati, A.A.; Qualtrough, A.J.; Watts, D.C. Endodontists experience using ultrasonics for removal of intra-canal fractured instruments. *Int. End. J.* **2010**, *43*, 301–305.
28. Atrizadeh, F.; Kennedy, J.; Zander, H. Ankylosis of teeth following thermal injury. *J. Periodontal. Res.* **1971**, *6*, 159–167. [CrossRef]
29. Nevares, G.; Cunha, R.S.; Zuolo, M.L.; Bueno, C.E. Success rates for removing or bypassing fractured instruments: A prospective clinical study. *J. Endod.* **2012**, *38*, 442–444. [CrossRef]
30. Shiyakov, K.K.; Vasileva, R.I. Resonance compatibility between endosonic tips and ultrasonic devices of different brands. *J. IMAB Annu. Proc.* **2014**, *20*, 621–625. [CrossRef]
31. Vieira, T.M.; Cardoso, R.M.; Alves, N.C.C.; Emanuel, A.; Conrado de Menezes, S.; Batista, S.M.; Silva, S.A.; Velozo, C.; Albuquerque, D.S.; Monteiro, G.Q.M. Cyclic fatigue resistance of blue heat-teated instruments at different temperatures. *Int. J. Biomater.* **2021**, *2021*, 5584766. [CrossRef]
32. Olivieri, J.G.; Duran-Sindreu, F. Root dentine thickness and concavity depth in mandibular molars: A cone beam computed tomography population study. *Eur. Endod. J.* **2018**, *3*, 160–166. [CrossRef]
33. Cen, R.; Wang, R.; Cheung, G.S.P. Periodontal blood flow protects the alveolar bone from thermal injury during thermoplasticized obturation: A finite element analysis study. *J. Endod.* **2018**, *44*, 139–144. [CrossRef]
34. Lempel, E.; Kincses, D.; Szebeni, D.; Jordáki, D.; Lovász, B.V.; Szalma, J. Intrapulpal temperature changes during the cementation of ceramic veneers. *Sci. Rep.* **2022**, *12*, 12919. [CrossRef]
35. Suter, B.; Lussi, A.; Sequeira, P. Probability of removing fractured instruments from root canals. *Int. Endod. J.* **2005**, *38*, 112–123. [CrossRef]