Abstract: Ultrasonic irrigation and syringe irrigation were compared for their efficacy at cleaning root canal in vivo and in vitro. The in vivo study used 60 anterior teeth or premolars from 60 patients with periapical periodontitis who were randomly assigned to a syringe irrigation group (group S) or an ultrasonic irrigation group (group U). After instrumentation with a K-file using the step-back technique, the two groups received ultrasonic or syringe irrigation using 40 mL of 2.5% NaOCl respectively, followed by conventional lateral compaction. The in vitro study used 60 extracted single-canal premolars, which were also divided into U and S groups, and underwent the same irrigation and compaction. Forty of them were evaluated histologically by light microscopy, and the remaining 20 by scanning electron microscopy. No difference in main root canal filling was observed between the U and S groups. Notably, group U had a larger number of obturated lateral canals than group S. Moreover, a smaller amount of organic debris and more open dentinal tubules were observed in the root canal in group U than in group S. Our findings suggest that ultrasonic irrigation has a greater capacity to clean instrumented root canals than syringe irrigation. (J Oral Sci 58, 373-378, 2016)

Keywords: ultrasonic irrigation; lateral canal; smear layer; root canal therapy; syringe irrigation.

Introduction

Endodontic therapy, also termed root canal therapy, involves removal of infected tissue and protection of decontaminated teeth (1). The root canal system has a complicated anatomical structure, comprising several irregular structures in the root canal wall. Therefore, root canal irrigation is of great importance for eliminating infected pulp tissue, and removing the smear layer and dentinal debris resulting from root canal filing (2,3). The efficacy of irrigation relies on both the flushing action of the irrigant and its capacity to dissolve infected tissue (4).

The application of ultrasonic devices to endodontics was first proposed by Richman in 1957. Ultrasonically activated files usually oscillate at frequencies (25-30 kHz) exceeding human hearing. There are two types of ultrasonic irrigation, with or without simultaneous ultrasonic instrumentation: ultrasonic instrumentation (UI) and passive ultrasonic irrigation (PUI). PUI without the requirement for simultaneous ultrasonic instrumentation is a non-cutting methodology in which the acoustic energy is transmitted from an ultrasonically oscillating
file to the irrigant solution flushing the root canal, thereby leading to acoustic streaming and cavitation of the irrigant, and facilitating greater and easier penetration of the irrigant into the apical part of the root canal (5,6). There is evidence that PUI could give rise to an increase in irrigant temperature and an enhanced tissue-dissolving effect in comparison to passive irrigant placement, irrespective of canal location and angulation (7). As a supplementary disinfection procedure, it could decrease the incidence of bacterial infection (8). Furthermore, it has been reported that the efficacy of PUI can be positively associated with ultrasonic intensity by regulating the amplitude of the file (9). Nonetheless, others have pointed out that PUI might be more complicated, dangerous and expensive than manual dynamic irrigation, based on the results of a study using an in vitro apex model (10). Considering these disagreements regarding the application of PUI, more research on its benefits and disadvantages should be encouraged.

Syringe irrigation has been used for decades in clinical practice (11,12). In comparison, however, ultrasonic irrigation achieves better removal of artificially created dentinal debris from simulated canal irregularities in the root canal following preparation (13). Results from scanning electron microscopy (SEM) observations support the superiority of PUI over syringe irrigation for elimination of debris from the root canal, even with a lower concentration of sodium hypochlorite (NaOCl) solution (14). In order to promote understanding of the clinical application of ultrasonic irrigation, the present in vivo and in vitro study compared the clinical, histological and ultrastructural effects of ultrasonic irrigation and syringe irrigation for root canal cleaning. It is anticipated that our findings would further clarify the clinical potential of ultrasonic irrigation for root canal therapy.

Materials and Methods

Procedure

The study included 60 patients diagnosed as having periapical periodontitis by a dentist at our hospital. From these patients, 60 mandibular premolars with a single straight canal and complete foramina were selected and randomized into two groups using random numbers generated by a computer: an ultrasonic irrigation group (group U) and a syringe irrigation group (group S).

The working length was established by deducting 1 mm from the actual canal length determined by inserting a #10 K-file into the canal until the tip of the file barely appeared visible at the apical foramen. All the pre-molars in the two groups were instrumented by a series of K-files using the step-back enlargement technique with circum-ferential filing in accordance with a previous study (15). The master apical file, which was three sizes larger than the initial apical file, was used for each pre-molar. Between each file size, a 5-mL syringe and a 27-gauge needle (Shan Dong Weigao Group Medical Polymer Company, Weihai, China) were placed 1 mm short of the working length for irrigating each canal with 1 mL of a freshly prepared 17% solution of ethylene diamine tetraacetic acid (EDTA) and 1 mL of a 2.5% solution of NaOCl, respectively.

After the canal instrumentation, group U was treated with ultrasonic irrigation using 40 mL of 2.5% NaOCl and Odontonson-M ultrasonic instruments (GOOF, Herlev, Denmark). After switching on the ultrasound device set at the manufacturer’s recommended power setting, a #15 ultrasonic file was placed at the border between the lower third and middle third of the root canals. The oscillation was performed in bucco-lingual direction for 2 min without the ultrasonic file binding to the canals walls. The 2.5% NaOCl solution was delivered at a rate of 20 mL/min through the ultrasonic file. For syringe irrigation, each root canal in group S was rinsed with the same amount (40 mL) of 2.5% NaOCl solution using a 5-mL syringe and a 27-gauge needle (Shan Dong Weigao Group Medical Polymer Co., Ltd., Weihai, China). The tip of the needle was placed at the border between the lower third and middle third of the root canals.

Following irrigation, each tooth in the two groups was rinsed with 2 mL of distilled water in order to stop the effect of the irrigant. The canals in the two groups were dried and then filled with a gutta-percha master cone coated with AH Plus root canal sealer (Dentsply DeTrey, Konstanz, Germany) employing the cold lateral compaction technique in accordance with previous studies (16-18).

An X-ray film was taken for each premolar before, during and after the procedure. The incidence of pain, quality of root canal filling and the number of obturated lateral canals were analyzed and compared between the two groups. The quality of root canal filling was evaluated based on the following criteria (19): adequate filling: root canal filling ≥2 mm short of the radiographic apex; inadequate filling: root canal filling >2 mm short of the radiographic apex (under-filling) or extending beyond the radiographic apex (overfilling). These procedures were performed by one operator. All procedures had been approved by Clinical Trial Ethics Committee of Qingdao Municipal Hospital (#2016-01), and were performed in accordance with ethical standards. Written informed consent was obtained from each patient.
**Histological analysis**

A total of 40 extracted single-canal premolars were randomly divided into groups U and S for histological analysis following the aforementioned procedure of root canal irrigation and filing. Prior to hematoxylin and eosin (HE) staining, all the samples were decalcified, cut into transverse cross-sections and embedded in paraffin. The HE-stained sections were observed using a light microscope (Olympus BH2, Tokyo, Japan). For each premolar, the amount of organic debris left in each root canal was single-blindly analyzed in three sections obtained from the apical, middle and cervical third of the root canal, respectively, employing a video imaging CMIAS Win system (20). The average amount for the three parts was defined as the amount of organic debris of the premolar.

**SEM observation of open dentinal tubules**

Similarly, 20 extracted single-canal premolars were randomly assigned to groups U and S, and subjected to the aforementioned root canal filing and irrigation procedures. These teeth were longitudinally split for SEM observation. Pictures of the cervical, middle and apical thirds were randomly taken and analyzed in a single-blind manner. The number of open dentinal tubules in the three parts was calculated using the Miriam algorithm (21) and averaged for each tooth.

**Statistical analysis**

Data in the study were expressed as median ± standard deviation ($\bar{X} \pm SD$). Statistical analysis was performed using SPSS 11.0 software (SPSS, Chicago, IL, USA). Categorical data were compared between the two groups using chi-squared ($\chi^2$) test. Student’s $t$-test was employed to analyze the quantitative data. $P < 0.05$ was considered to indicate significant differences.

**Results**

**Clinical effects of ultrasonic and syringe irrigation**

The *in vivo* study included 60 premolars from 60 patients. Demographic data for the 60 patients are summarized in Table 1. There were no significant differences in sex, age, or teeth between the two groups ($P > 0.05$). As shown in Table 2, group U had a markedly shorter irrigation time than group S (241.50 ± 27.61 s vs. 123.03 ± 2.20 s; $P < 0.001$). No significant difference in the incidence of pain was observed between the two groups (Table 2).

The quality of root canal filling was compared between groups U and S. There was no significant inter-group difference in main root canal filling ($P > 0.05$, Table 3). However, as shown in Table 4, group U had significantly more obturated lateral canals than group S ($P < 0.01$). Three typical cases from group U are displayed in Figs. 1-3, respectively.

**Histological and ultrastructural analysis**

Histological analysis using HE staining was performed for evaluating the effect of ultrasonic and syringe irrigation on root canal cleaning using 40 extracted single-canal premolars. As shown in Table 5, group U had a markedly smaller amount of organic debris in the root canals than group S ($P < 0.01$; Fig. 4, Table 5).

Ultrasound analysis was done using 20 extracted premolars with a single canal. SEM observation displayed more visible open dentinal tubules in group U than in...
group S ($P < 0.01$; Fig. 5, Table 5).

**Discussion**

Root canal irrigation is an important and indispensable component of successful endodontic therapy. Ultrasonic irrigation has been investigated by a number of researchers and clinical practitioners. This study found that group U had higher percentages of obturated lateral canals, lower amounts of organic debris left in the root canals, and more open dentinal tubules than group S. These findings provided evidence that ultrasonic irrigation had a greater capacity to clear instrumented root canals than syringe irrigation.

NaOCl has been widely used as a non-toxic endodontic irrigant due to its ability to dissolve organic tissue and kill microorganisms (3,22). The efficacy of irrigation is predominantly reliant on the flushing action of the irrigant and its dissolution capacity. Syringe irrigation is not sufficient for producing a strong flushing action. In contrast, ultrasonic irrigation produces a much more powerful flushing action characterized by acoustic streaming and cavitation effects, which help to remove biofilm and extricate debris from prepared root canals (23). This may be one reason for the superiority of ultrasonic irrigation over syringe irrigation for root canal cleaning.

After chemo-mechanical preparation processes, tissue remnants might be left in root canals, forming an amorphous structure known as the smear layer, which clings to the root canal wall. The impact of the smear layer on

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**Table 4** Comparison of lateral canal filling between the two groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group S (n = 30)</th>
<th>Group U (n = 30)</th>
<th>$X^2$</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral canal root canal filling</td>
<td>2 (7)</td>
<td>8 (27)</td>
<td>4.320</td>
<td>0.038</td>
</tr>
</tbody>
</table>

**Table 5** Assessment of organic debris and open dentinal tubules of two groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group S (n = 30)</th>
<th>Group U (n = 30)</th>
<th>$t$</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>The amount of organic debris</td>
<td>0.142 ± 0.146</td>
<td>0.0143 ± 0.023</td>
<td>3.864</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Dentinal tubules</td>
<td>91.21 ± 34.91</td>
<td>133.14 ± 14.35</td>
<td>3.122</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>
the quality of root canal instrumentation and filling is controversial. A number of investigations have shown that removal of the smear layer exacerbates the penetration of bacteria into the dentinal tubules (24-26), suggesting that the smear layer might serve as a barrier against bacterial infection. Nonetheless, others argue that the smear layer might compromise the therapeutic effect of intra-canal medications by impeding the penetration of medications into the dentinal tubules, thus protecting bacteria already present there (27-29). Besides, the smear layer itself may also be infected by bacteria located within dentinal tubules. Therefore, it is considered prudent to eliminate the smear layer covering the infected root canals. The results of this study showed that considerably more open dentinal tubules were present in group U than in group S, indicating that ultrasonic irrigation was more effective than syringe irrigation for removing the smear layer in instrumented root canals.

It was demonstrated that groups U and S had a similar quality of main root canal filling, whereas significantly more obturated lateral canals were observed in group U than in group S. This difference might have been due to the different irrigation methods employed in the two groups. Ultrasonic irrigation might remove dentinal debris and tissue remnants more effectively, and eliminate the smear layer adhering to root canal walls, thus exposing more lateral canals and permitting the penetration of root canal filling material. In accordance with this, it has been found that ultrasonic irrigation promotes the penetration of irrigant solution into lateral canals and achieves better root canal system debridement (30). Furthermore, histological analysis demonstrated that less organic debris was left in group U than in group S, adding further evidence that ultrasonic irrigation had a greater potential to clean the root canal than syringe irrigation. It has been found that a synergistic effect between a mid-range ultrasonic wave and 2.5% NaOCl results in an enhanced ability to dissolve tissue and kill bacteria (31). This synergistic effect might be another reason for the remarkable cleaning ability of ultrasonic irrigation.

Collectively, our present findings suggest that ultrasonic irrigation with 2.5% NaOCl could more effectively eliminate dentinal debris, remove the smear layer, and expose more lateral canals and dentinal tubules than syringe irrigation. Ultrasonic irrigation is recommended as an effective method in clinical practice for root canal debridement following root canal instrumentation. Further studies with a larger sample size are needed to confirm the present results.

Conflict of interest
The authors declare that they have no competing interests.

References

Fig. 4 Observation of organic debris in the root canal by light microscopy (magnification ×4). In group U, only a small amount of organic debris is evident in the apical third (A) of the root canal, whereas almost no organic debris is present in the middle (B) and cervical (C) thirds. In group S, a large amount of organic debris is evident in the apical third (D) of the root canal, whereas a smaller amount of organic debris is present in the middle (E) and cervical (F) thirds.

Fig. 5 SEM observation of dentinal tubules in groups U and S (magnification ×1,500). (A) A large number of open dentinal tubules are visible without the presence of organic debris or a smear layer in the apical third in group U. (B) In group S, the majority of dentinal tubules are covered by organic debris or a smear layer.
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