INTRODUCTION

Peri-radicular diseases may persist or emerge following the completion of root canal treatment as a result of intra-radicular infection, extra-radicular infection or non-microbial factors. The main cause of failure is persistent, or recurrent microbial infection. Non-surgical retreatment is usually the preferred option for teeth in which endodontic treatment has failed as there is a greater opportunity to eradicate any intra-radicular source of infection compared with a surgical approach. Retreatment comprises removal of the old root filling material to allow access to any residual micro-organisms and permit further cleaning and disinfection of the root canal system. Additionally, efficient removal of previous filling materials can facilitate intimate contact between the sealer and the root canal walls, thus potentially preventing microleakage.

Gutta percha is the most commonly used root canal filling due to its favourable properties such as dimensional stability, biocompatibility and ease of removal. However, it does not bond to sealer. A resin-based root canal filling, Resilon, was launched in 2004. It is capable of bonding to methacrylate-based sealers and as such may result in the prevention of microleakage and strengthening of the root treated tooth.

Root filling materials can be removed by a variety of techniques such as the use of stainless steel or nickel-titanium hand files, nickel-titanium rotary files or ultrasonic instruments with or without the adjunctive use of solvents or heat. Studies have compared the effectiveness of either rotary to hand instrumentation or compared different rotary systems. The combined use of hand instruments and rotary files for effective removal of filling materials has been advocated, but no study has investigated the effectiveness of a combination of the two.

Several studies have investigated the ease of removal of Resilon compared with gutta percha. So far, however, there has been no published data related to the relationship between removal success and method of filling technique (i.e. cold lateral condensation versus thermal obturation).

The aim of this study, therefore, was to investigate the effectiveness of rotary instrumentation and its combination with hand instrumentation in the removal of gutta percha and Resilon placed into root canals by either cold lateral condensation or thermal technique using micro-CT. The null hypothesis was that there would be no significant difference in the removability between the tested materials, techniques of obturation and techniques of removal.

MATERIALS AND METHODS

Ethical approval for this study was obtained from the Ethics Committee at the University of Manchester. Ninety-six upper anterior teeth were prepared using ProTaper files and allocated into four groups (n=24): Group-1 was filled with GP/AH-Plus and Group-2 with Resilon/RealSeal using cold lateral condensation. Group-3 was filled with GP/AH-Plus and Group-4 with Resilon/RealSeal using System B and Obtura II. The roots were scanned by micro-CT. Each group was divided into two subgroups (n=12): A, retreated using ProTaper files and B, using ProTaper retreatment and K-files. The roots were scanned to calculate the volume of the remaining material. With thermal obturation, roots filled with Resilon had significantly more remaining material than GP. Obturation using thermal technique resulted in significantly less remaining material than cold condensation except Resilon retreated using ProTaper retreatment and K-files.

Keywords: Computed tomography (CT), Gutta percha, ProTaper, Retreatment, Resilon
lateral incisors and 24 canines) were selected according to the criteria noted above. Teeth were decoronated and root lengths were reduced to 14 mm using a diamond wheel saw with water cooling (Model 650, South Bay Technology Inc., California, USA). Central incisors, lateral incisors and canines were kept separate to facilitate in their allocation into groups for obturation. The working length was determined to be 1 mm short of the apical foramen using a size 10 K-file (Quality Endodontic Distributors Ltd, Peterborough, UK). A glide path was established and the canals were prepared using rotary ProTaper Universal files (Dentsply Maillefer, Ballaigues, Switzerland) to size F3. The motor used was an X-smart (Dentsply Maillefer, Ballaigues, Switzerland) with a contra angle hand-piece. The canals were irrigated with 1 mL 1% NaOCl (Procter and Gamble, Weybridge Surrey, UK) after each filing. When the preparations were completed, the root canals were irrigated with 5 mL 17% ethylene-diamine-tetra-acetic acid (EDTA) (PPH Cerkamed, Sandomierska, Poland) and 10 mL distilled water.

**Obturation of root canals**

The roots were randomly allocated into four groups using stratified sampling (n=24, 12 central incisors, 6 lateral incisors and 6 canines) based on the material and technique of obturation:

- **Group 1 (GP/C)** was filled with ProTaper gutta percha/AH-Plus sealer (Quality Endodontic Distributors Ltd, Peterborough, UK) using cold lateral condensation. A suitable master cone (fitted the canal to the working length with tug-back) was selected and the canal was dried using paper points. The sealer was applied using the master cone. A finger spreader (Dentsply Maillefer, Ballaigues, Switzerland) was used to compact the cone and accessory points were inserted into the resulting space until obturation was completed. The gutta percha points were cut to the coronal end of the root using a heated instrument and the coronal part was condensed using a Machtoù plugger (Dentsply Maillefer, Ballaigues, Switzerland).

- **Group 2 (R/C)** was filled with Resilon/RealSeal (SybronEndo, Glendora, USA) sealer using cold lateral condensation. A master cone of size 30/0.06 was selected. RealSeal primer was applied and the excess was removed using paper points. The sealer was applied using the master cone. Lateral condensation was completed as described for Group 1. The coronal surface was light cured for 40 s as recommended by the manufacturers.

- **Group 3 (GP/T)** was filled with ProTaper gutta percha/AH-Plus sealer using continuous wave of compaction technique. A System B plugger of fine-medium size (SybronEndo, Glendora, USA) was used and a rubber stopper was adjusted to 5 mm short of the working length. The temperature was set to 200°C in the touch mode. The excess GP was cut using the hot plugger which was then inserted alongside the master cone until the rubber stopper reached a reference point. The heat application was then stopped and apical pressure was maintained for 10 s. The plugger was withdrawn after one-second activation of the heat source. Backfilling was performed using Obtura III at 200°C (Quality Endodontic Distributors Ltd, Peterborough, UK).

- **Group 4 (R/T)** was obturated with Resilon/RealSeal sealer using System B and Obtura III as explained for Group 3. Temperature in System B and Obtura III was set to 150°C according to the manufacturers’ instructions. All roots were stored in air-tight containers for a week at 37°C and 100% humidity. All the root fillings were carried out by one operator.

**Scanning of the roots**

Teeth were scanned in random order using a Nikon micro-CT (225 kV 3 µm source) (X-tek Systems Ltd., Tring, England) housed in a customised bay. Images were collected on a 2,000 pixel detector using a sample-source distance of 2 cm and a sample-detector distance of 138 cm which allowed observation of fine differences in contrast. The target material could be changed which allowed adjustment of the X-ray attenuation by accelerating voltage. Copper was chosen as the target material. The micro-CT settings were: 93 kV, 135 microAmps, 1901 projections (radiographs), 1000 s exposure, gain 16.

**Retreatment**

Each group was divided into two subgroups (n=12, 6 central incisors, 3 lateral incisors and 3 canines). In both subgroups, the coronal 2 mm of the filling was removed using Gates Glidden drills (3 and 4) (Quality Endodontic Distributors Ltd, Peterborough, UK). Then, two drops of eucalyptus oil (PPH Cerkamed, Sandomierska, Poland) were placed in the space made available. In subgroup A, the filling material was removed using rotary ProTaper Universal files (F1, F2 and F3) (at 300 rpm) and in subgroup B using rotary ProTaper Universal retreatment files (D1, D2 and D3) (Quality Endodontic Distributors Ltd, Peterborough, UK) (at 500 rpm as per the manufacturer’s recommendation) followed by hand K-files (25 and 30). ProTaper Universal and retreatment files were used at the following penetration depths: F1 and D1 to the coronal third, F2 and D2 to the middle third and F3 and D3 to the apical third. In subgroup B, hand K-files (25 and 30) were used to the full working length in a circumferential quarter-turn push-pull motion. The criteria for completion of the treatment were clean canal walls and no material on the files as observed by the naked eye. When treatment completed, irrigation was performed using 3 mL 1% NaOCl, 5 mL 17% EDTA and finally, 10 mL distilled water. Root canals were dried using paper points. All the retreatment work was carried out by one operator.

**Scanning of the roots**

The Nikon micro-CT was used to scan the roots for the second time using the same settings as for the first scan. The raw data from the first and second scan were reconstructed using CTPro 3D software (Version XT 2.2, Metris, Hertfordshire, UK). A voxel size of 7.7–9.3 µm was obtained. Using Avizo 6.3 Standard version...
(Visualization Sciences Group, Berlin, Germany), the total filling and the remaining material were viewed in three-dimensional images. The total volume of filling was measured from the data of the first scan and the total volume of the remaining material from the second scan. The percentage of the volume of the remaining material was then calculated.

**Statistical analysis**

SPSS Version 20.0 (IBM Corp., Armonk, US) was used with the level of significance set at $p \leq 0.05$. Data were found to be not normally distributed and therefore, nonparametric tests were used. Analysis of data was carried out using Kruskal-Wallis test with multiple pairwise comparisons.

**RESULTS**

Table 1 shows means and standard deviations of the overall percentage volume of remaining material. Resilon/cold lateral group (R/C) retreated using ProTaper Universal rotary files showed the highest percentage volume of remaining material (3.94%) and gutta percha/thermal group (GP/T) retreated using ProTaper Universal rotary files showed the least percentage (1.34%). When the thermal obturation technique was used, teeth filled with Resilon were found to have significantly more remaining material than gutta percha when they were removed using ProTaper Universal retreatment files and hand K-files ($p=0.028$) and using ProTaper Universal files ($p=0.013$). There was no significant difference between Resilon and gutta percha when the cold lateral condensation technique was used.

On comparison of the techniques of obturation, the continuous wave of compaction resulted in significantly less remaining material than the cold lateral condensation technique in all groups except the Resilon group retreated using ProTaper Universal retreatment files and hand K-files ($p=0.004$ for the gutta percha group retreated using ProTaper Universal files and $p=0.018$ for the Resilon group retreated using ProTaper Universal files). There was no significant difference between the retreatment techniques used.

As shown in Table 2, the remaining material in the apical third was found to be significantly more than in the middle and the coronal thirds in all groups. Figure 1 illustrates reconstructed three-dimensional images for a representative sample filled with gutta percha before and after retreatment.

**Table 1** Means and standard deviations (SD) of the overall percentage volume of remaining material in the tested groups

<table>
<thead>
<tr>
<th>Obturation technique</th>
<th>Filling/Retreatment technique</th>
<th>Gutta percha</th>
<th>Resilon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>P</td>
<td>PH</td>
</tr>
<tr>
<td>Cold lateral condensation</td>
<td>2.80 (0.37)</td>
<td>2.85 (0.62)</td>
<td>3.94 (1.50)</td>
</tr>
<tr>
<td>Continuous wave of compaction</td>
<td>1.34 (0.33)</td>
<td>1.45 (0.40)</td>
<td>2.06 (0.64)</td>
</tr>
</tbody>
</table>

P: ProTaper Universal files, PH: ProTaper retreatment files and hand K-files. The two obturation techniques are significantly different except with Resilon when removed by PH. Resilon is significantly different from gutta percha when continuous wave of compaction technique used irrespective to the removal technique.

**Table 2** Means and standard deviations (SD) of the percentage volume of remaining material in each third of the root canal in the tested groups

<table>
<thead>
<tr>
<th>Obturation technique</th>
<th>Filling/Retreatment technique</th>
<th>Gutta percha</th>
<th>Resilon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>P</td>
<td>PH</td>
</tr>
<tr>
<td>Cold lateral condensation</td>
<td>Coronal</td>
<td>0.24 (0.12)</td>
<td>0.12 (0.08)</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>0.63 (0.32)</td>
<td>0.50 (0.26)</td>
</tr>
<tr>
<td></td>
<td>Apical</td>
<td>1.93 (0.60)</td>
<td>2.23 (0.67)</td>
</tr>
<tr>
<td>Continuous wave of compaction</td>
<td>Coronal</td>
<td>0.05 (0.03)</td>
<td>0.03 (0.02)</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>0.18 (0.08)</td>
<td>0.32 (0.25)</td>
</tr>
<tr>
<td></td>
<td>Apical</td>
<td>1.11 (0.31)</td>
<td>1.10 (0.27)</td>
</tr>
</tbody>
</table>

P: ProTaper Universal files, PH: ProTaper retreatment files and hand K-files. The apical third is significantly different form the other two thirds in all groups.
DISCUSSION

The present study showed that when Resilon was removed significantly more material remained than in teeth filled with gutta percha when a continuous wave of compaction technique was used. It was also found that obturation using the cold lateral condensation technique resulted in significantly more remaining material than the continuous wave of compaction technique after removal in all groups except the Resilon group retreated using ProTaper Universal retreatment files and hand K-files. Removability of Resilon in comparison with gutta percha has been previously investigated using different retreatment techniques. However, no study has compared the outcome of removal of the two root filling materials when placed into the canal using different techniques. In addition, the effectiveness of the combined use of hand and rotary instrumentation has not been examined before. Very few studies have used micro-CT to measure the volume of the remaining material. In this study, micro-CT was used as it gives an accurate three-dimensional image of the remaining material.

Resilon matrix is composed of co-polymers of polycaprolactone and urethane dimethacrylate. The dimethacrylate component enables Resilon to be bonded to various dual-cure methacrylate-based resin sealers which in turn bond to the root canal dentine forming a “monoblock”. By contrast, gutta percha, which is composed of zinc oxide and gutta percha, does not bond to any type of sealers. This may explain the significantly greater volume of Resilon remaining compared with gutta percha found when the thermal obturation technique was used. Similar results have been reported in previous studies, but contradictory results have also been found. It has been reported that complete setting of RealSeal sealer takes about 30 min in an anaerobic environment, but may take one week in an aerobic field. In the study by Hammad et al., the time allowed for the sealer to set was 72 h, whereas in this study, the roots were stored for a week. Therefore, the low volume of Resilon reported in the former study may be attributed to the incomplete setting of the sealer.

But why was the difference between Resilon and gutta percha significant only with the thermal obturation technique and not with the cold lateral obturation technique? It has been reported that softened Resilon flows better than gutta percha into lateral canals. Therefore, there would be more residual Resilon than gutta percha in the lateral canals after removal. In addition, it has been found that eucalyptus oil is more effective on thermoplastic gutta percha than conventional gutta percha and this may explain the results obtained in this study.

It was found that obturation using cold lateral condensation resulted in significantly more residual material than the continuous wave of compaction after removal in all groups except the Resilon group retreated using ProTaper Universal retreatment files and hand K-files. The latter technique may require a smaller quantity of sealer and form a more homogenous mass than the former. Hence, there would be a lesser amount of sealer to be eliminated and easier removal of the homogenous mass. When ProTaper Universal retreatment files and hand K-files were used, the difference between the two obturation techniques with Resilon was not significant. This may be attributed to the equal effectiveness of this technique in removal of Resilon with both obturation techniques. Previous studies which compared the effectiveness of hand with rotary instrumentation reported contrasting results. This may be due to differences in the rotary systems tested, type of hand file and time allowed for setting of sealers. The current study found no significant difference in the effectiveness of removal between ProTaper Universal rotary files and the combined use of ProTaper Universal retreatment files and hand K-files. The retreatment in the ProTaper Universal groups was performed up to a file size F3, whose tip size is 30, and to size 30 hand K-file in the combined ProTaper Universal retreatment files and hand K-files groups. The standardization of the size of the apical enlargement may explain the insignificant difference found.

The results of this study showed that the remaining material in the apical third was significantly more than the middle and coronal thirds in all tested groups. This was in agreement with previous studies which investigated different retreatment techniques. During retreatment, the material in the coronal and middle thirds is more accessible via both mechanical and chemical removal techniques than the material in the apical third. In addition, the material may be pushed to the apical third during removal. Furthermore, the root
canal anatomy in the apical third is complicated with lateral canals and ramifications which make complete removal of the filling material very difficult. Micro-CT was used in this study as it has been shown that it gives a highly accurate, non-destructive, three-dimensional view of the internal structure of the root. Other methods of assessment used in earlier studies such as radiographs, splitting or clearing of roots may not be accurate as they only yield partial evaluation of the remaining material. Variations in the anatomy of the human teeth such as lateral canals and other root canal ramifications may influence the removal of the filling material. However, the roots were randomly allocated into groups and therefore they were equally affected. As this is an in vitro study, caution should be exercised when these results are extrapolated to a clinical situation. The percentages of the remaining material shown in this study, although significantly different, are actually small (1.84–3.94%) and clinical studies are needed to see if these differences are clinically significant.

CONCLUSION

The current findings show that re-treatment of teeth filled with Resilon resulted in more residual material than those filled with gutta percha when a thermal compaction technique was used. This may highlight the need for meticulous care if this resin-based root filling material needs to be removed. Removal of Resilon and gutta percha from teeth filled using cold lateral condensation resulted in more residual material than those filled using thermal compaction. The combined use of rotary and hand instrumentation may not be superior to rotary instrumentation alone if the size of apical enlargement in retreatment, in relation with the primary treatment, is considered.

ACKNOWLEDGMENT

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REFERENCES