A comparative evaluation of the increase in root canal surface area and canal transportation in curved root canals by three rotary systems: A cone-beam computed tomographic study

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Abstract

Aim: The aim of this study was to measure the increase in root canal surface area and canal transportation after biomechanical preparation at 1, 3, and 5 mm short of the apex with three different rotary systems in both continuous rotary and reciprocating rotary motions.

Materials and Methods: Sixty freshly extracted human mandibular molars with mesial root canal curvatures between 20° and 30° were included in the study. Teeth were randomly distributed into three groups (n = 20). Biomechanical preparations were done in all the mesial canals. In Group 1, instrumentation was done with ProTaper universal rotary files, Group 2, with K3XF rotary files, and Group 3, with LSX rotary files. Each group was further subdivided into subgroups A and B (n = 10) where instrumentation was done by continuous rotary and reciprocating rotary techniques, respectively. Increase in root canal surface area and canal transportation was measured using the preoperative and postoperative cone-beam computed tomography scans.

Statistical Analysis: The data were analyzed by one-way ANOVA followed by Tukey pairwise multiple comparison tests.

Results: Increase in root canal surface area was significantly more (P < 0.05) in ProTaper and K3XF groups when compared to LSX group. Canal transportation was significantly more (P < 0.05) in ProTaper group when compared to K3XF and LSX groups. There was no significant difference (P > 0.05) in increase of root canal surface area and canal transportation between continuous rotary and reciprocating rotary techniques for ProTaper Universal, K3XF and LSX groups.

Conclusion: LSX rotary system showed minimal increase of root canal surface area and minimal canal transportation when compared to ProTaper and K3XF rotary systems.

Keywords: Canal transportation; cone-beam computed tomography; Ni-Ti; root canal surface area

INTRODUCTION

The main drawback with the traditional stainless steel files is their inability to follow the canal curvature with a tendency to straighten, particularly at the start of the curvature.1,2 Ni-Ti instruments introduced in 1988 to endodontics showed super-elasticity and shape memory.3 The main problems with instruments used in continuous rotary motion are the instrument separation caused by cyclic fatigue and inability of the instrument to maintain canal curvature. An alternative...
for continuous rotary is a reciprocating rotary instrument that travels shorter angular distance in one direction and reverses its direction before completing a full rotation, thereby subjecting the instrument to lower stress values. As a result, an instrument has an extended fatigue life when used in reciprocation as opposed to rotary motion.\(^{[4-8]}\)

Cone beam computed tomography (CBCT) is a recent advancement with advantages of image accuracy, acquisition of images in three planes (coronal, sagittal and axial) and reduced image artifacts.\(^{[9-11]}\)

The ProTaper rotary system has an active file design without radial lands. The K3XF system has an active file design with radial lands. The LightSpeed system has a passive file design with radial lands. These rotary systems were selected because of their versatility in designs.

The null hypothesis tested was that increase in root canal surface area and canal transportation may not vary between rotary systems with different designs in either continuous rotary or reciprocating rotary motions.

**MATERIALS AND METHODS**

Sixty freshly extracted human mandibular molars from patients of age group 40 to 50 years with fully formed apices, absence of root caries, cracks, and structural defects with mesial root canal curvatures in distal direction between 20\(^\circ\) and 30\(^\circ\) (Schneider’s method) and those with initial minimum working width of 0.1 mm were selected for analysis so that apical enlargement can be done uniformly to the same size in all the teeth. Teeth with minimum working width of >0.15 mm were excluded from the study. Modeling wax was manipulated and adapted into a stock tray. Into each wax mounting, the radicular portions of five teeth were embedded, leaving the crowns oriented upward so that they are accessible for the endodontic procedure.

**Cone-beam computed tomography scanning procedure**

Pre- and post-instrumentation scans were performed using CBCT (Kodak 9000, Kodak Carestream Health, Trophy, France) and all the scans were conducted with a 4 cm field of view, at 0.125 mm voxel resolution with 60 kV and 2.5 mA.

**Endodontic procedure**

After preoperative scanning, access cavities were prepared and working length (WL) was established 0.5 mm short of the apex. Teeth were randomly divided into three groups (\(n = 20\)). Glide path was established with #10K-file in all the samples. Manual instrumentation was not done prior to the use of mechanical instrumentation as the purpose of this study was to measure the canal transportation with different rotary systems. Recapitulation was done with one size smaller hand K-file corresponding to the rotary file.

**Irrigation protocol**

During instrumentation, 17% ethylenediaminetetraacetic acid (Prime Dental Products Pvt. Ltd., India) was used as a lubricant and, after every instrumentation, irrigation was done with 2 ml of 3% NaOCl (Prime Dental Products Pvt Ltd, India) in all groups.

**Biomechanical preparation**

Instrumentation was started with SX file up to half of the working length (WL) and proceeded with S1 file up to two thirds the working length, and S2 file to the complete WL. The SX and S1 instruments were used at 300 rpm and 3 Ncm torque, followed by instruments S2, F1, and F2 up to the working length, at 250 rpm and 2 Ncm torque, avoiding apical pressure and applying gentle strokes against the canal walls.

1. **Group 1**: ProTaper group, 20 teeth were made into two subgroups (\(n = 10\))
   - Subgroup A: Instrumentation of mesial canals was done by continuous rotary technique with ProTaper Universal rotary files (Dentsply Maillefer, Ballaigues, Switzerland) connected to X-Smart endomotor (Dentsply Maillefer, Switzerland) according to the manufacturer’s instructions
   - Subgroup B: Instrumentation was done by reciprocating rotary technique with ProTaper rotary files connected to Waveone endomotor (Dentsply Maillefer, Switzerland) according to the manufacturer’s instructions following the same irrigation protocol as in subgroup A.

2. **Group 2**: K3XF group, 20 teeth were made into two subgroups (\(n = 10\))
   - Subgroup A: Instrumentation was done by continuous rotary technique with K3XF rotary files (SybronEndo, Glendora, CA, USA) connected to X-Smart endomotor according to the manufacturer’s instructions up to ISO size 25 and 06% taper
   - Subgroup B: Instrumentation was done by reciprocating rotary technique with K3XF rotary files connected to Waveone endomotor following the manufacturer’s instructions up to ISO size 25 and 06% taper.

3. **Group 3**: LSX group, 20 teeth were made into two subgroups (\(n = 10\))
   - Subgroup A: Instrumentation was done in crown down method by continuous rotary technique with LSX rotary files (LightSpeed Technology Inc., San Antonio, TX, USA) connected to TCM Endo V endomotor (Nouvag). The speed was set at 2000 rpm. Initially, #15, #20 LSX files were used, and then #25 LSX file was used up to the WL. All the teeth were selected with initial minimum working width of 0.1 mm and apical enlargement was done up to three sizes larger than the initial apical file i.e., upto ISO size 25\(^{[12]}\)
   - Subgroup B: Instrumentation was done by reciprocating rotary technique with LSX rotary files connected to Waveone endomotor following the same protocol as in subgroup A.
Assessment of the increase in root canal surface area
Adobe Photoshop software [Figure 1a] was used to export and evaluate the preoperative [Figure 1b] and postoperative CBCT images [Figure 1c] (axial sections). The surface area of root canals at three different levels, i.e., at 1, 3, and 5 mm cross-sections was measured according to the protocol given by Özer. The difference between the post- and pre-operative values represented the increase in root canal surface area at that cross-section [Figure 1d].

Assessment of apical transportation
The distances from the root canal outline to the external surface of root were measured in all the four directions, both preoperatively and postoperatively as per the method suggested by Gambill et al.[14] [Figure 1e and f]. To standardize the procedure and avoid variations in results, a single operator conducted the study. The data obtained were subjected to statistical analysis.

Differences in increase of root canal surface area and canal transportation between groups were analyzed by one-way analysis of variance, followed by Tukey pairwise multiple comparison tests.

RESULTS
In both mesiobuccal and mesiolingual canals, increase in root canal surface area was significantly more between ProTaper Universal and LSX groups, K3XF , and LSX groups. There was no significant difference between ProTaper Universal and K3XF groups at 1, 3, and 5 mm cross-sections at 1 mm, 3 mm and 5 mm cross-sections in both continuous rotary and reciprocating rotary techniques.

Increase of root canal surface area was not significant (P = 1.000) for any given rotary system in this study when used in either continuous rotary or reciprocating rotary techniques at all the three levels [Table 1].

Mesio-buccal and mesio-lingual canals were analysed independently in all the samples. Individual canals vary both in angle of curvature and radius of curvature but were not measured as it was not the aim in the present study. However measurement of canal curvature and radius of curvature in all the three dimensions is possible only with µ-CT. Increase in root canal surface area and canal transportation in both the mesial canals was clinically significant but was not statistically significant. In both of the mesial canals, canal transportation was significantly

![Figure 1](image-url)
more between ProTaper Universal and K3XF groups, K3XF and LSX groups, and ProTaper Universal and LSX at all the three cross-sections both in continuous rotary and reciprocating rotary techniques.

Canal transportation was seen in mesial direction in all the samples, i.e., opposite to the direction of canal curvatures for all the rotary systems used. Canal transportation was clinically as well as statistically significant. Canal transportation is inversely related to the remaining dentin thickness. More the canal transportation less will be the remaining dentin thickness. This parameter was not measured as it was not the aim in the present study.

Increase in canal transportation was not significant ($P = 0.986$) for any given rotary system in this study when used in either continuous rotary or reciprocating rotary techniques at all the three levels [Table 2].

## DISCUSSION

Increase in root canal surface area and canal transportation was measured at 1 mm, 3 mm and 5 mm short of the apex as this was the region most crucial with respect to canal aberrations.

Transportation of the root canal is considered to be an important parameter to assess the root canal preparation, particularly in curved root canals. Severe canal transportation associated with an over reduction of sound dentin along the inner aspect in the middle part and along the outer aspect in the apical part of the root canal may result in a marked reduction of the fracture resistance of enlarged root canals.\cite{15}

The effect of reciprocating rotary technique on increase of root canal surface area and canal transportation has not been well investigated, and very few studies compared the canal transportation in continuous rotary and reciprocating rotary techniques.\cite{16} Hence, the present study was aimed at determining the increase in root canal surface area and canal transportation in both continuous rotary and reciprocating rotary techniques.

On comparison of the increase in root surface area between ProTaper Universal and K3XF groups, there was no significant difference ($P > 0.05$) at all the three cross-sections. This might be because both groups were enlarged to the same apical diameter (0.25 mm) and both of them had a positive rake angle for efficient cutting.

While comparing increase in root canal surface area between ProTaper Universal, K3XF, and LSX groups, it showed that there was a significant increase in root canal surface area ($P < 0.05$) for ProTaper Universal and K3XF groups when compared to LSX group. This might be because the length of cutting portion of LSX files was greatly reduced (0.5–2 mm) with no taper, presence of small radial lands, and noncutting tip whereas ProTaper and K3XF systems had positive rake angle that led to increased cutting of dentin. Similar results were reported by Rao et al.\cite{17} where they found that least amount of dentin was

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Table 1: Tukey pairwise multiple comparison tests to determine the significant increase in root canal surface area between the groups at 5, 3, and 1 mm for mesiolingual canal

| Dependent variable | 5 mm |  |  | 5 mm |  |  |  |  |  |  |  |  |
|-------------------|------|---|---|------|---|---|---|------|---|---|---|---|
|                   | Mean difference (SE) | Lower bound | Upper bound | Mean | 95% CI | Lower bound | Upper bound | Mean | 95% CI | Lower bound | Upper bound | Mean | 95% CI | Lower bound | Upper bound |
| ProTaper rotary    | 0.62 (0.03) | −0.705 | −0.535 | −0.08 (0.02) | −0.213 | −0.131 | −0.021 | −0.14 (0.01) | −0.180 | −0.096 | −0.19 (0.01) | −0.228 | −0.144 |
| Lightspeed rotary  | 0.60 (0.03) | −0.715 | −0.545 | −0.07 (0.02) | −0.129 | −0.019 | −0.019 | −0.14 (0.01) | −0.182 | −0.098 | −0.19 (0.01) | −0.230 | −0.146 |
| PT reciprocating   | 0.61 (0.03) | −0.695 | −0.525 | −0.06 (0.02) | −0.125 | −0.015 | −0.015 | −0.12 (0.01) | −0.166 | −0.082 | −0.17 (0.01) | −0.214 | −0.130 |
| K3 rotary          | 0.64 (0.03) | −0.725 | −0.555 | −0.06 (0.02) | −0.102 | −0.019 | −0.019 | −0.14 (0.01) | −0.186 | −0.102 | −0.19 (0.01) | −0.234 | −0.150 |
| K3 reciprocating   | 0.62 (0.03) | −0.705 | −0.535 | −0.08 (0.02) | −0.131 | −0.021 | −0.021 | 0.14 (0.01) | 0.096 | 0.180 | 0.14 (0.01) | 0.098 | 0.182 |
| Lightspeed rotary  | −0.62 (0.03) | 0.000 | 0.537 | 0.07 (0.02) | 0.013 | 0.009 | 0.019 | −0.14 (0.01) | 0.000 | 0.119 | 0.14 (0.01) | 0.010 | 0.186 |
| PT reciprocating   | −0.63 (0.03) | 0.000 | 0.537 | 0.08 (0.02) | 0.017 | 0.012 | 0.012 | −0.16 (0.01) | 0.000 | 0.234 | 0.16 (0.01) | 0.000 | 0.234 |
| K3 rotary          | −0.61 (0.03) | 0.000 | 0.537 | 0.07 (0.02) | 0.013 | 0.012 | 0.012 | −0.14 (0.01) | 0.000 | 0.234 | 0.14 (0.01) | 0.000 | 0.234 |
| K3 reciprocating   | −0.64 (0.03) | 0.000 | 0.537 | 0.08 (0.02) | 0.017 | 0.012 | 0.012 | −0.16 (0.01) | 0.000 | 0.234 | 0.16 (0.01) | 0.000 | 0.234 |

SE: Standard error; CI: Confidence interval; PT: ProTaper; LS: LightSpeed.
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Table 2: Tukey pairwise multiple comparison tests to determine the significant increase in root canal transportation between the groups at 5, 3 and 1 mm for mesiolingual canal

| Dependent variable | 5 mm |  | 3 mm |  | 1 mm |  |
|--------------------|------|---|------|---|------|---|
|                    | Mean difference (SE) | P | 95% CI | Mean difference (SE) | P | 95% CI | Mean difference (SE) | P | 95% CI | Lower bound | Upper bound |
| ProTaper rotary     |      |   |       |   |       |   |       |   |       |   |   |   |
| K3 rotary          | 0.04 (0.01) | 0.001 | 0.012 | 0.066 | 0.06 (0.01) | 0.000 | 0.034 | 0.086 | 0.04 (0.01) | 0.919 | −0.056 | 0.028 |
| K3 reciprocating   | 0.05 (0.01) | 0.000 | 0.018 | 0.072 | 0.06 (0.01) | 0.000 | 0.035 | 0.087 | 0.05 (0.01) | 0.998 | −0.036 | 0.048 |
| Lightspeed rotary  | 0.07 (0.01) | 0.000 | 0.046 | 0.100 | 0.10 (0.01) | 0.000 | 0.071 | 0.123 | 0.07 (0.01) | 0.999 | −0.018 | 0.096 |
| LS reciprocating    | 0.07 (0.01) | 0.000 | 0.047 | 0.101 | 0.00 (0.01) | 0.000 | 0.071 | 0.123 | 0.07 (0.01) | 0.999 | −0.022 | −0.144 |
| PT reciprocating    |      |   |       |   |       |   |       |   |       |   |   |   |
| K3 rotary          | 0.02 (0.01) | 0.171 | −0.005 | 0.049 | 0.03 (0.01) | 0.008 | 0.006 | 0.058 | 0.02 (0.01) | 0.866 | −0.058 | 0.026 |
| K3 reciprocating   | 0.03 (0.01) | 0.038 | 0.001 | 0.055 | 0.01 (0.01) | 0.006 | 0.007 | 0.059 | 0.03 (0.01) | 1.000 | −0.039 | 0.046 |
| Lightspeed rotary  | 0.06 (0.01) | 0.000 | 0.029 | 0.083 | 0.06 (0.01) | 0.000 | 0.043 | 0.095 | 0.06 (0.01) | 0.999 | −0.182 | −0.098 |
| LS reciprocating    | 0.06 (0.01) | 0.000 | 0.030 | 0.084 | 0.06 (0.01) | 0.000 | 0.043 | 0.095 | 0.06 (0.01) | 0.999 | −0.230 | −0.146 |
| K3 rotary          | −0.04 (0.01) | 0.001 | −0.066 | −0.012 | −0.04 (0.01) | 0.000 | −0.086 | −0.034 | −0.04 (0.01) | 0.919 | −0.028 | 0.056 |
| PT reciprocating    | −0.02 (0.01) | 0.171 | −0.049 | 0.005 | −0.02 (0.01) | 0.008 | −0.058 | −0.006 | −0.02 (0.01) | 0.866 | −0.026 | 0.058 |
| Lightspeed rotary  | 0.03 (0.01) | 0.006 | 0.007 | 0.061 | 0.03 (0.01) | 0.001 | 0.011 | 0.063 | 0.03 (0.01) | 0.999 | −0.166 | −0.082 |
| LS reciprocating    | 0.04 (0.01) | 0.004 | 0.008 | 0.062 | 0.04 (0.01) | 0.001 | 0.011 | 0.063 | 0.04 (0.01) | 0.999 | −0.214 | −0.130 |

In the present study, canal transportation was significantly less in K3XF group (< 0.05) when compared to ProTaper Universal group. This might be because of the variable core diameter along the length of cutting portion of K3XF that led to maintenance of canal curvature.

Least canal transportation in LSX group might be because of the short cutting surface (0.5–2 mm) with small radial lands, neutral rake angle, smooth, flexible shaft, and noncutting tip that led to minimum canal deviation. The present study included teeth with moderate root canal curvatures (between 20° and 30°) as most of the mesiobuccal and mesiolingual root canals of mandibular molars were found to have moderate curvatures. [20]

In the present study, all the three groups showed canal transportation toward the outer side of root curvature at all the three apical cross-sections. This might be because of the tendency of these files to straighten. Similar results were reported by Ayar and Love [21] and Bergmans et al. [22,23] with ProTaper and K3 systems.

In the present study, there was statistically significant difference in increase of root canal surface area and canal transportation for the three rotary systems in either mesiobuccal and mesiolingual groups. This might be because of the short cutting surface (0.5–2 mm) with small radial lands, neutral rake angle, smooth, flexible shaft, and noncutting tip that led to minimum canal deviation. The present study included teeth with moderate root canal curvatures (between 20° and 30°) as most of the mesiobuccal and mesiolingual root canals of mandibular molars were found to have moderate curvatures.

In the present study, all the three groups showed canal transportation toward the outer side of root curvature at all the three apical cross-sections. This might be because of the tendency of these files to straighten. Similar results were reported by Ayar and Love [21] and Bergmans et al. [22,23] with ProTaper and K3 systems.
continuous rotary or reciprocating rotary motions. Hence, the null hypothesis was rejected.

Limitations of the present study include only teeth with moderate root canal curvatures were included and usage of manual method to measure the root canal surface area by counting the number of pixels using Adobe Photoshop software. Further research in teeth with severe root curvatures followed by ex vivo and in vivo studies are needed to confirm these results in a clinical scenario.

CONCLUSION

Increase in root canal surface area was significantly more in ProTaper Universal and K3XF groups when compared to LSX group. Canal transportation was significantly more in ProTaper Universal group when compared to K3XF and LSX groups. Canal transportation was also significantly more in K3XF group when compared to LSX group. There was no significant difference in increase of root canal surface area and canal transportation between the continuous rotary and reciprocating rotary techniques in all the three groups.

Uniformity in the increase of root canal surface area was better in LSX rotary system when compared to ProTaper Universal and K3XF rotary systems. LSX rotary system showed minimal canal transportation when compared to ProTaper Universal and K3XF rotary systems.

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Conflicts of interest
There are no conflicts of interest.

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