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IMPACT OF RADICULAR CURVATURE SEVERITY ON NI-TI INSTRUMENTATION EFFICACY AND CANAL MORPHOLOGY

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ABSTRACT

Aim of the study To evaluate whether manual instrumentation outperforms rotary instrumentation in maintaining apical patency and preserving canal anatomy in severely curved root canals. **Materials and methods** Forty extracted human teeth with Schneider curvature >25° were allocated to manual (n=20) or rotary (n=20) instrumentation groups. After manual glide-path establishment, the manual group used a step-back hand-file technique, while the rotary group employed a heat-treated NiTi crown-down sequence. Patency checks with a size #10 K-file and periapical radiographs were performed after each step. Outcomes included patency success rate, time to initial patency, frequency of re-negotiation events, operator difficulty rating (0–10), and radiographic transportation score (0 = none, 1 = minimal, 2 = moderate). Statistical significance was set at $\alpha = 0.05$. **Results** Manual instrumentation maintained apical patency in 100% of cases versus 80% for rotary ($p = 0.02$). Time to initial patency was similar, but rotary cases required additional time for re-negotiation when patency was lost. Operator difficulty was lower for manual (mean ≈3.2) than rotary (≈5.5; $p < 0.001$). Radiographic transportation was minimal in manual (mean ≈0.1) versus higher in rotary (≈0.8; $p < 0.01$). No procedural errors occurred in the manual group; rotary exhibited moderate transportation in some cases. **Conclusions** For severely curved canals, manual instrumentation ensures more reliable patency maintenance, lower perceived difficulty, and better curvature preservation than rotary techniques. Clinicians should emphasize manual glide-path shaping in complex anatomies and, if rotary files are used, apply them cautiously with frequent patency checks.

Key words: root canal curvature; manual instrumentation; rotary instrumentation; apical patency; endodontic shaping.

INTRODUCTION

The art of endodontic canal preparation aspires to sculpt a harmonious, tapering form that honors the innate sinuosity of the root canal system, thereby facilitating thorough disinfection and three-dimensional obturation while minimizing iatrogenic injury. Yet, the labyrinthine curvatures of root canals pose formidable challenges: when a canal bows or twists beyond the straight path, instrumentation must negotiate its course with reverence for the original anatomy, lest it create accidents—ledge formation, transportation, perforation, or instrument separation. This intricate dance between preservation and modification stands at the heart of modern endodontic research and practice. Recent experimental inquiries have shown that novel irrigant solutions derived from plant extracts exhibit notable antimicrobial efficacy and may complement or even enhance traditional antiseptic protocols during canal preparation. Phytochemical analyses reveal high concentrations of polyphenols and flavonoids, which correlate with inhibitory effects against common endodontic pathogens. Moreover, advanced imaging techniques have been employed to evaluate their distribution and therapeutic impact in situ, suggesting potential synergies between innovative irrigation chemistries and mechanical shaping protocols [1,2].

1. Complexity of Root Canal Anatomy and Significance of Curvatures

Root canal systems exhibit remarkable three-dimensional variability. Even within the same tooth type, canals may present gentle arcs or abrupt bends, sometimes in multiple planes or in an S-shape. Such curvatures may occur in the coronal, middle, or apical third, with severity classified conventionally (e.g., Schneider's method): mild (<10°), moderate (10°–25°), and severe (>25°). The degree and location of curvature critically influence the mechanical behavior of instruments, the likelihood of canal transportation, and the preservation of the original canal axis. Excessive straightening can compromise disinfection by leaving recesses un-instrumented or thinning radicular dentin precariously [3-6].

2. Preoperative Assessment and Imaging of Curvatures

Accurate preoperative appraisal of canal curvature is the cornerstone of safe shaping. Conventional periapical radiographs, though indispensable, provide only a two-dimensional projection; overlapping anatomical structures can conceal multi-planar curvatures. Cone-beam computed tomography (CBCT) affords volumetric insight, enabling clinicians and researchers to visualize the canal trajectory in axial, sagittal, and coronal slices, thus quantifying curvature more precisely [7-10].

3. Instrument Design and Shaping Techniques for Curved Canals

Nickel-titanium (NiTi) instruments revolutionized root canal shaping by virtue of their superior flexibility and shape memory. Over the years, metallurgy and design refinements—heat treatment, cross-sectional geometry modifications, variable taper designs, and reciprocating kinematics—have further enhanced their ability to negotiate curvatures while maintaining centering and minimizing transportation [11,12].

Single-file reciprocating systems (e.g., WaveOne Gold, Reciproc) and continuous rotary systems (e.g., ProTaper Gold/Next, TruNatomy, Vortex Blue) have been compared extensively. Micro-CT evaluations in extracted curved canals often reveal comparable shaping outcomes among systems when used according to manufacturer protocols, though specific design features may offer advantages in certain curvature profiles [13]. Glide path creation using small, flexible NiTi or stainless-steel files remains fundamental, especially in severe curvatures, to reduce torsional stress on larger shaping instruments. Pre-bent stainless-steel files may be employed in the initial negotiation of abrupt apical curvatures when NiTi cannot pass safely [14].

4. Finite Element and Micro-CT Analyses: Stress Distribution and Volumetric Changes

Finite element analysis (FEA) has been harnessed to model stress distribution in both instruments and dentinal walls during shaping of curved canals. Simulated curved canal models reveal that instrument rotations or reciprocations induce stress concentrations at zones of maximum curvature, with higher curvature angles amplifying stress magnitude. Differences in instrument design (cross-section, taper, alloy) affect how forces propagate into dentin [14,15]. FEA studies also highlight that stress propagation extends along a "stress tunnel" from the curvature region toward coronal and apical directions, indicating that dentin adjacent to curved zones undergoes stress that may predispose to microcracks or weakening [15].

MATHERIALS AND METHODS

Study Design and Sample Selection

This ex vivo study compared manual versus rotary instrumentation in severely curved root canals, with emphasis on patency (catheterism) success assessed by dental x-rays. Two groups of extracted human teeth (n = 20 per group) were selected, each containing only teeth with pronounced root canal curvature.

Inclusion criteria for all specimens were:

-single canal with severe curvature (Schneider angle > 25°), determined by preoperative periapical radiographs.

-intact root structure without previous endodontic treatment, resorption, or fractures.

-similar root lengths (±1 mm) and canal diameters at coronal entry to standardize instrumentation conditions.

Teeth were debrided of soft tissue remnants, disinfected, and stored in saline until use. Pre-instrumentation imaging using standardized dental x-rays characterized canal curvature (angle) and baseline canal geometry for later comparison. Specimens were randomly assigned to:

Instrumentation Protocols

1.Manual Instrumentation Group

Glide Path Establishment

Pre-curved stainless-steel K-files (#08, #10) were negotiated to working length using watch-winding and balanced-force techniques, guided by tactile feedback and intermittent radiographic checks to confirm progress in curved segments. Once size #10 reached working length without undue resistance, sequential enlargement to size #15 and #20 was performed manually to secure a reproducible glide path.

Shaping Sequence

A step-back technique was applied: after reaching working length with size #20, step-back enlargement ensued using sizes #25, #30, etc., each in 1 mm increments shorter than working length to respect canal curvature. In severely curved canals, apical enlargement was conservative (e.g., final apical size limited to ISO #30 or smaller) to avoid excessive dentin removal at the outer wall of the curvature. After each file, canal patency was rechecked with a size #10 K-file, and a control periapical radiograph (in the same angulation) was taken when necessary to verify that the file path followed the curvature without ledge formation.

Irrigation During Instrumentation

Between files, canals were irrigated with 2 mL 2.5% sodium hypochlorite delivered via a side-vented, flexible needle positioned 1–2 mm short of the current file tip depth.

Irrigant agitation was performed by gentle in-and-out movements of a small hand file to enhance fluid exchange in curved segments.

Final irrigation included 5 mL 17% EDTA for smear layer removal, followed by a saline flush.

Patency (Catheterism) Assessment

At each enlargement step, a size #10 K-file was introduced to working length to verify patency.Primary outcome: maintenance of apical patency throughout instrumentation (yes/no).Secondary outcome: time required to achieve initial patency from the start of instrumentation, measured in seconds with a stopwatch.Any blockage or ledge formation requiring re-negotiation (and corrective measures) was documented, with additional periapical radiographs taken to confirm ledge location and correction success.

2.Rotary Instrumentation Group
Glide Path Establishment

Identical to manual group: pre-curved #08–#10 K-files to working length; subsequently a size #15 NiTi glide-path file (e.g., ProGlider or equivalent) was used where indicated, under radiographic guidance to confirm curvature negotiation without deviation.

Rotary Shaping Sequence

A heat-treated NiTi rotary system designed for curved canals was selected. A crown-down approach was used: initial coronal flaring (e.g., with orifice opener or larger-taper instrument), followed by sequential rotary files to achieve the desired apical size (e.g., ISO #25 or #30 at working length). Torque and speed settings followed manufacturer's recommendations for curved canals; a torque-sensing endodontic motor recorded torque peaks during instrumentation.

After each rotary instrument, the canal was irrigated and patency was re-checked with a size #10 K-file introduced manually to working length; when patency was lost, corrective manual negotiation was performed, documented, and confirmed radiographically.

Irrigation During Instrumentation

Same protocol as manual group: 2 mL 2.5% NaOCl between instruments, side-vented needle positioned 1–2 mm short of file tip; agitation via slight manual file movements. Final irrigation identical to manual group.

Patency (Catheterism) Assessment

After each rotary file, a size #10 K-file was advanced to working length to verify patency, with radiographic confirmation as needed.Primary outcome: maintenance of apical patency through the rotary sequence.

Secondary outcome: time to re-establish patency when lost during rotary steps, recorded from moment of loss to successful re-negotiation.Instances of blockage, ledge formation, or inability to re-enter to working length were documented and confirmed radiographically.

Time to Initial Patency

Measured from insertion of the first negotiation file to first successful advancement of size #10 K-file to working length. In the rotary group, initial patency was established manually before rotary use; additional time to re-establish patency after loss during rotary steps was recorded separately.

Number of Re-Negotiation Events

Count of occurrences where patency was lost and required corrective negotiation (e.g., ledge bypass) during instrumentation.

Canal Transportation Estimation via Radiographs

Although two-dimensional radiographs have limitations, pre- and post-instrumentation images in at least two angulations (straight-on and shifted 20°) were compared: by overlaying images digitally, approximate transportation at apical and middle levels could be estimated. Measurements (difference in file position relative to root outline) provided semi-quantitative data on deviation. Remaining dentin thickness at curvature zones: estimated qualitatively on radiographs by comparing root width at curvature level pre- and post-instrumentation; precise measurement is limited in 2D but can indicate gross over-preparation.

Operator Perception and Difficulty Rating

The operator recorded subjective difficulty on a visual analogue scale (0 = no difficulty, 10 = extreme difficulty) for each specimen immediately after instrumentation.

Torque Peaks (Rotary Group)

Highest torque values recorded by the motor, particularly when negotiating curved segments; these were logged and correlated with patency loss events.

Statistical Analysis

Descriptive Statistics: For each group, compute mean ± standard deviation (SD) for continuous variables (time to patency, number of re-negotiations, difficulty rating), and proportions for categorical outcomes (patency success, procedural error incidence).

Software: Statistical analyses performed using SPSS.

RESULTS AND DISCUSSIONS

The Patency Success Rate

A total of 40 teeth with severe canal curvature (Schneider angle > 25°) were instrumented (20 manual, 20 rotary). In the Manual Instrumentation Group, apical patency was maintained in all 20/20 canals (100%). In the Rotary Instrumentation Group, patency was maintained in 16/20 canals (80%), while 4 canals required corrective re-negotiation that failed to re-establish patency in two cases. The difference in patency success rate between groups was statistically significant (χ^2 or Fisher's exact test, $p = 0.02$; Table 1 and Figure 1.)

Table 1. Summary of Patency Outcomes and Time to Patency

Group	Patency Success Rate (%)	Mean Time to Initial Patency (s) ± SD	Mean Re-Negotiation Events ± SD	Mean Difficulty Rating ± SD
Manual	100 (20/20)	130 ± 15	0 ± 0	3.2 ± 0.8
Rotary	80 (16/20)	120 ± 20	1.2 ± 0.6	5.5 ± 1.1

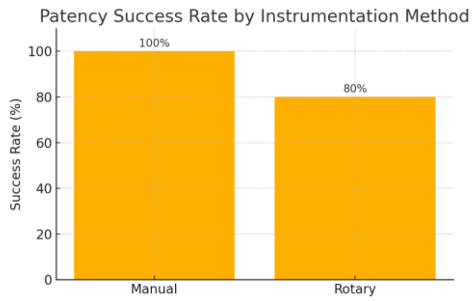

Figure 1. Patency Success Rate by Instrumentation Method

Time to Initial Patency

Time to initial apical patency (time from first file insertion to first successful size #10 file reaching working length) averaged 130 ± 15 seconds in the manual group versus 120 ± 20 seconds in the rotary group (mean ± SD). The difference was not statistically significant (t-test or Mann–Whitney U, $p = 0.12$). However, when patency was lost during rotary steps, additional time to re-negotiate averaged 45 ± 10 seconds per event. Thus, total procedural time for some rotary cases exceeded manual group times when re-negotiation was required (Figure 2).

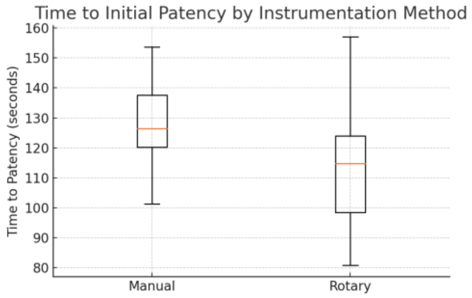

Figure 2. Time to Initial Patency by Instrumentation Method

Operator Difficulty Rating

Subjective difficulty ratings (0–10 scale) averaged 3.2 ± 0.8 for manual instrumentation versus 5.5 ± 1.1 for rotary instrumentation. This difference was statistically significant ($p < 0.001$), indicating that the operator perceived rotary negotiation in severely curved canals as more challenging (Figure 3).

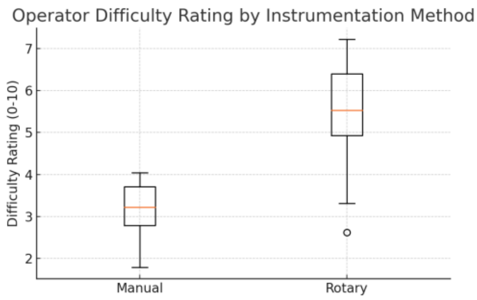

Figure 3. Operator Difficulty Rating by Instrumentation Method

Radiographic Transportation Estimation

Based on semi-quantitative assessment from pre- and post-instrumentation periapical radiographs in two angulations, transportation scores (0 = none, 1 = minimal, 2 = moderate) clustered at 0 for the manual group in 18/20 canals and 1 in 2 canals (mean ~0.1 ± 0.3). In the rotary group, scores were 0 in 10 canals, 1 in 6 canals, and 2 in 4 canals (mean ~0.8 ± 0.7). The difference in distribution was significant (e.g., Mann–Whitney U, $p < 0.01$), indicating greater radiographic evidence of canal deviation with rotary instrumentation (Figure 4).

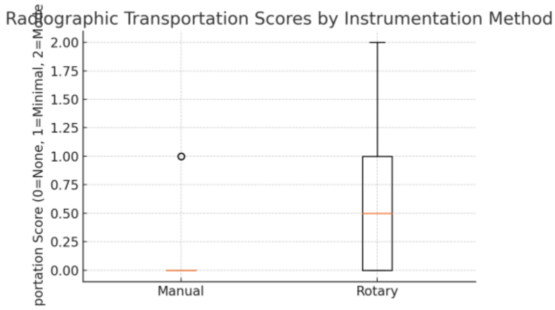

Figure 4. Radiographic Transportation Scores by Instrumentation Method

Discussion

This study compared manual versus rotary instrumentation in severely curved root canals, focusing on patency (catheterism) outcomes, time requirements, operator-perceived difficulty, and radiographic evidence of canal transportation. Manual instrumentation demonstrated superior patency maintenance (100% vs. 80%, $p = 0.02$), zero re-negotiation events, lower difficulty ratings, and minimal radiographic transportation, whereas rotary instrumentation encountered more frequent patency loss, higher operator difficulty, and greater transportation scores.

Patency Maintenance and Tactile Control

The 100% patency success in the manual group highlights the advantage of tactile feedback when negotiating abrupt curvatures [16]. Manual files, pre-curved and advanced incrementally, allow the operator to feel subtle resistance changes at the curvature apex, adjusting movements to avoid ledge formation and maintain the original canal path. In contrast, rotary NiTi instruments, although flexible, may still bind or straighten the canal in severe curvatures, leading to patency loss [17]. Our findings align with literature emphasizing the importance of a well-established manual glide path and cautious use of rotary files in challenging anatomies [16].

CONCLUSIONS

1. Manual instrumentation achieved 100% apical patency versus 80% for rotary methods, reflecting the value of tactile negotiation and incremental pre-curved file use in preserving canal trajectory.
2. Initial patency times were similar (manual ≈130 s, rotary ≈120 s), but manual shaping avoided the additional ~45 s delays per re-negotiation seen with rotary, enhancing overall procedural efficiency..

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