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In Vitro Comparison of TruNatomy and Conventional Needle Irrigation for Root Canal Debris Removal

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Abstract **Background:** Effective root canal irrigation plays a crucial role in endodontic success by facilitating debris removal and enhancing disinfection. Conventional Needle Irrigation (CNI) remains widely used despite its limitations in effectively cleaning the apical third. The TruNatomy (TRN) flexible irrigation needle has been introduced as an alternative, designed to improve fluid dynamics and optimize debris removal. This *In vitro* study aims to compare the efficacy of TRN and CNI in debris removal from simulated root canals. **Methods:** Thirty-six artificial root canals in resin blocks were randomly divided into two groups (n = 18 each): the conventional needle irrigation group using a 30-G side-vented needle and the TruNatomy group using a flexible irrigation needle. Irrigation was performed with 5 ml 2.5% sodium hypochlorite (NaOCl) for 90 seconds, followed by a final rinse with 17% EDTA for one minute and saline irrigation. Digital imaging was used to quantify debris removal by superimposing a 160-square grid onto post-instrumentation images. Two independent evaluators assessed the debris and Cohen's kappa statistic (0.82) confirmed interrater reliability. Statistical analysis was conducted using the Mann-Whitney U-test, with significance set at $p<0.05$. **Results:** The TruNatomy needle demonstrated significantly better debris removal at 1 mm from the working length compared to conventional needle irrigation. The mean debris percentage in the TRN group was 2.26% (±0.35), whereas the conventional needle group exhibited 5.3% (±0.91) ($p<0.001$). Additionally, the mean number of debris pixels in the TRN group was significantly lower (10.8±1.7) than in the conventional needle group (25.8±4.3, $p<0.001$). **Conclusions:** TruNatomy flexible irrigation needle significantly improved debris removal in simulated root canals, particularly in the apical third, when compared to conventional needle irrigation. However, since this study was conducted using resin blocks, which lack the anatomical complexity of natural root canals, the findings should be interpreted with caution. Further *in vivo* studies are necessary to validate these results in clinical scenarios and assess the long-term impact of TruNatomy irrigation on endodontic treatment outcomes.

Key Words Root canal debris, TruNatomy, Conventional needle irrigation, Endodontic irrigation, Debris removal

INTRODUCTION

Minimally invasive endodontics is a contemporary approach aimed at preserving as much of the natural tooth structure as possible while achieving optimal clinical outcomes. It focuses on maintaining pericervical dentin, a critical area for transferring occlusal forces, thereby reducing stress on the coronal structure. The concept was first introduced by Clark and Khademi [1] and has since gained substantial support through various studies demonstrating its role in minimizing post-endodontic cracks and root fractures [2-5]. While the approach was initially applied to constricted access cavity preparation and guided access, it has now been extended to minimally prepared root canal spaces [6]. The TruNatomy (TRN) file system was developed to align with these principles by preserving structural dentin and tooth integrity while ensuring efficient shaping and cleaning [7].

A key challenge in endodontic treatment is achieving effective disinfection and cleaning of the root canal system. Mechanical instrumentation alone is often insufficient for removing all debris, particularly in the apical third [8]. Root canal irrigation plays a crucial role in reducing microbial loads and facilitating debris removal, yet its effectiveness depends on factors such as irrigant type, volume, concentration, contact time and delivery method. Due to the anatomical complexity of the apical third and the difficulty in fully instrumenting this region [8], various irrigation techniques have been developed to enhance debris removal and optimize chemo-mechanical preparation [9]. Advanced irrigation technologies have emerged to address the limitations of conventional syringe irrigation, aiming to improve the penetration, distribution and agitation of irrigants within the root canal. Some of these technologies include sonic irrigation systems like EndoActivator (MAN), mechanical agitation systems such as XP-Endo (MAN), negative pressure systems like EndoVac (Discus Dental, Culver City, CA) and ultrasonic activation devices including PiezoFlow (ProUltra; Dentsply, Tulsa, OK). Other emerging methods involve laser-activated irrigation (MAN) and continuous ultrasonic irrigation systems (VPro StreamClean System, Vista Dental Products, Racine, WI), all designed to enhance irrigant effectiveness in complex root canal anatomies [10-14].

The TruNatomy irrigation needle is a two-sided vented, soft plastic needle specifically designed to deliver a concentrated stream of irrigant directly to the apical third while easily navigating complex canal curvatures. Conventional needle irrigation, despite its limitations in fluid dynamics and irrigant penetration, remains the most widely used method due to its simplicity, low cost and broad availability. Studies indicate that many clinicians still rely on conventional needle irrigation despite the availability of more advanced alternatives [15]. Recent computational fluid dynamics studies suggest that conventional irrigation is particularly compromised in minimally prepared root canal spaces, where standard 30-G and 31-G side-vented needles fail to deliver irrigants effectively to the full working length, regardless of the applied flow rate [16]. These findings highlight the need for further experimental validation of alternative irrigation methods to improve debris removal in minimally shaped canals.

Research Gap and Justification

Although various advanced irrigation techniques have been explored in the literature, most studies focus on ultrasonic and sonic activation rather than flexible needle designs. Computational fluid dynamics studies suggest that conventional 30-G and 31-G irrigation needles struggle to deliver irrigants to the working length in minimally prepared canals [16]. Given the increasing emphasis on minimally invasive endodontics, where canal preparation sizes are reduced to preserve dentin and prevent structural weakening, it is critical to evaluate whether TruNatomy's flexible design improves debris removal compared to conventional irrigation methods. This study seeks to fill this gap by providing an experimental, quantitative comparison of debris removal using TruNatomy and conventional needle irrigation.

Objective and Hypothesis

This study aims to compare the efficacy of TruNatomy flexible irrigation needles and conventional needle irrigation in removing debris from simulated root canals. The hypothesis guiding this research is that "TruNatomy irrigation removes debris more effectively than conventional needle irrigation, particularly in the apical third of the root canal.

Significance of the Study

By assessing the effectiveness of these two irrigation techniques, this study will contribute valuable insights to clinical decision-making in endodontics. If TruNatomy proves superior, it could offer a more efficient and safer alternative to conventional irrigation, particularly in complex or minimally prepared canals. However, given that *In vitro* studies may not fully replicate clinical conditions, further research, including clinical trials, will be necessary to validate these findings and determine the practical implications for endodontic practice.

MATERIALS AND METHODS

Study Design

This *In vitro* study aimed to evaluate the efficacy of TruNatomy flexible irrigation needles compared to conventional needle irrigation in removing debris from artificial root canals. Resin blocks were chosen to ensure uniformity in canal morphology and standardization of working length, facilitating reproducible experimental conditions. While resin blocks offer consistency, they do not fully replicate the complex anatomy and material properties of natural teeth, which may limit the direct applicability of the results to clinical scenarios. Therefore, further *in vivo* studies are necessary to validate these findings.

Sample Selection

A total of 36 simulated root canals in clear resin blocks, each with a 30-degree curvature and 16 mm length, were selected for the study. The sample size was determined based on a power analysis, aiming for a power of 80% ($\beta = 0.2$) and an alpha level of 0.05, to detect significant differences between groups. The samples were randomly allocated into two groups:

- **Conventional Needle Irrigation (CNI) group:** 18 canals irrigated using a 30-G side-vented needle (Dentsply Sirona)
- **TruNatomy Flexible Irrigation Needle (TRN) group:** 18 canals irrigated using the TruNatomy flexible irrigation needle (Dentsply Sirona, Ballaigues, Switzerland)

While resin blocks provide a standardized testing medium, they lack the anatomical variability and structural characteristics of natural teeth, which may influence the generalizability of the results.

Canal Instrumentation

All canal preparations were performed by a single operator to eliminate inter-operator variability. The working length was established at 0.5 mm short of the apical foramen. Instrumentation was conducted using a crown-down technique without irrigation, employing RACE® EVO rotary files (FKG Dentaire, La-Chaux-de-Fonds, Switzerland) in the following sequence:

- 0.15/0.04
- 0.20/0.04
- 0.25/0.04

A 16:1 reduction handpiece powered by an electric motor (E-connect endo motor, Eighteenth, Changzhou City, Jiangsu Province, China) was used at a torque of 2.5 Ncm and 350 rpm. A glide path was established using a size #10 K-file (Dentsply Sirona) prior to rotary instrumentation.

Irrigation Protocol

Following instrumentation, each canal underwent an irrigation protocol as follows:

- **Initial irrigation:** 5 ml of 2.5% sodium hypochlorite (NaOCl) with mechanical agitation for 90 seconds
  - **CNI group:** Irrigation using a 30-G side-vented needle positioned 1 mm short of the working length
  - **TRN group:** Irrigation using the TruNatomy flexible irrigation needle positioned 1 mm short of the working length
- **Final irrigation sequence for both groups:**
  - 17% EDTA for one minute
  - Saline rinse for 90 seconds using a conventional needle

Canals were subsequently dried with absorbent paper points of matching sizes.

Debris Quantification

To simulate debris, red dye acrylic paint was applied to the canals post-instrumentation. Pre-irrigation images were captured at 40x magnification using a stereomicroscope (SMZ-10, Nikon, Tokyo, Japan). Post-irrigation, images were taken at 5.5x magnification to visualize the entire canal length, which was divided into coronal, middle and apical thirds. Each segment was imaged at 40x magnification, resulting in three images per canal.

A 160-square grid was superimposed on each post-instrumentation image to assess debris presence. Two independent, blinded evaluators scored the images using a 5-point scale:

- **Score 1:** No debris
- **Score 2:** <25% debris coverage
- **Score 3:** 25-50% debris coverage
- **Score 4:** 50-75% debris coverage
- **Score 5:** >75% debris coverage

The number of debris particles per square and per pixel was recorded. The average of 25 scores per image was rounded to the nearest integer for analysis, following established methodologies.

Inter-Observer Reliability

To ensure consistency and minimize bias, two independent, blinded evaluators assessed the debris images. Inter-observer agreement was measured using Cohen's kappa statistic, yielding a coefficient of 0.82, which indicates strong agreement.

Statistical Analysis

The Kolmogorov-Smirnov test assessed data normality, revealing a non-normal distribution. Consequently, the Mann-Whitney U-test was employed to compare median debris percentages and counts between groups. Statistical significance was set at $p<0.05$. No missing data were reported and outliers were managed according to standard protocols to maintain data integrity.

RESULTS

Following the final irrigation protocol, the TruNatomy flexible irrigation needle (TRN) group demonstrated a significantly lower amount of residual debris compared to the Conventional Needle Irrigation (CNI) group. Quantitative analysis revealed that the TRN group had a mean debris percentage of 2.26% (±0.35), whereas the CNI group exhibited a higher mean debris percentage of 5.3% (±0.91). This difference was statistically significant ($p<0.001$).

In terms of debris count per pixel, the TRN group showed a mean of 10.8 (±1.7) debris particles, markedly lower than the 25.8 (±4.3) particles observed in the CNI group, with this reduction also being statistically significant ($p<0.001$).

To further interpret the magnitude of these differences, the effect size was calculated using the rank-biserial correlation coefficient (r). The effect size for debris percentage was $r = 0.75$ and for debris count per pixel, $r = 0.78$. According to conventional benchmarks, these values indicate a large effect size, suggesting that the type of irrigation needle has a substantial impact on debris removal efficacy.

Table 1 provides a detailed summary of the mean and median values for both debris percentage and debris count per pixel across the two irrigation methods.

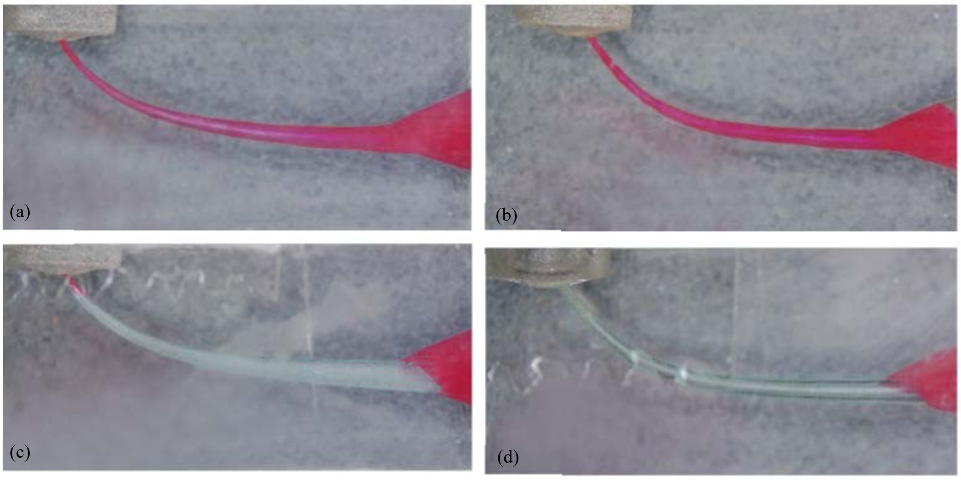

Figure 1: Simulated canal images pre- and post-irrigation, (a) Before irrigation with conventional needle, (b) After irrigation with conventional needle, (c) Before irrigation with TruNatomy flexible needle and (d) After irrigation with TruNatomy flexible needle

Table 1: Comparison of debris percentage and debris count per pixel between irrigation methods

Irrigation method	Debris percentage	Debris count per pixel
	Mean (SD)	Mean (SD)
Conventional Needle	5.3 (±0.91)	25.8 (±4.3)
TruNatomy Flexible Needle	2.26 (±0.35)	10.8 (±1.7)
	Median (IQR)	Median (IQR)
Conventional Needle	4.06 (3.1, 5.9)	19.5 (15, 28.2)
TruNatomy Flexible Needle	1.9 (1.2, 3.2)	9.5 (5.5, 15.2)
	$p<0.001$	$p<0.001$

SD: Standard deviation, IQR: Interquartile range

Visual assessments corroborated these findings. Figure 1(a and c) depict the simulated canals before irrigation using conventional and TruNatomy needles, respectively. Post-irrigation images (Figure 1(b and d)) illustrate a noticeable reduction in residual debris in the TRN group compared to the CNI group.

These results suggest that the TruNatomy flexible irrigation needle is more effective in reducing residual canal debris compared to conventional needle irrigation methods.

DISCUSSION

Effective removal of debris from the root canal system is essential for successful endodontic treatment, combining the mechanical action of instruments with the chemical effects of irrigants and the physical processes of irrigation and aspiration [17]. Despite advances in endodontic technology, current methods cannot completely eliminate root canal debris. Irrigation plays a vital role in decontamination and studies have demonstrated the efficacy of sodium hypochlorite (NaOCl), ethylenediaminetetraacetic acid (EDTA) and chlorhexidine when delivered via syringe and needle [18,19]. However, numerous studies have reported that debris often remains, particularly in the apical third, where delivery mode is a critical factor in effectiveness [20-23].

Various irrigation devices and needle-tip designs have been developed to enhance irrigant distribution [24,25]. The TruNatomy (TRN) irrigation needle, a non-metallic, side-vented, flexible polypropylene needle, is designed to navigate complex canal anatomies more effectively than conventional side-vented needles. This study aimed to experimentally compare the TRN needle with conventional needle irrigation in the removal of root canal debris in an *In vitro* setting.

The study findings support previous literature showing that conventional needle irrigation is less effective in apical areas than coronal regions [26,27]. Irrigation effectiveness improves when the needle is positioned closer to the apex [28] and when lower-gauge needles are used [29]. In this study, a final apical file size of #25/.04 was chosen because it allowed both TRN and conventional side-vented needles to be placed at 1 mm short of the Working Length (WL) [30].

Our results showed that the TRN needle achieved significantly superior debris removal compared to conventional side-vented needles, particularly in the apical third. The mean debris remaining in the TRN group was 2.26% (\u00b10.35), significantly lower than the 5.3% (\u00b10.91) observed in the conventional needle group. This aligns with studies indicating that flexible, tapered and thinner irrigation needle designs enhance fluid dynamics, leading to improved irrigant penetration and debris clearance, especially in curved and apical regions [31].

Given these findings, we recommend positioning the TRN needle within 1 mm of the WL to maximize irrigant replacement and optimize cleaning efficiency. The side-vented design of both needles prevents direct apical ejection, enhancing safety [32]. However, it is important to acknowledge that irrigation effectiveness is also influenced by operator skill, root canal morphology and flow dynamics, factors not fully replicated in an *In vitro* model.

Evaluation of debris removal in endodontic research commonly utilizes techniques such as Scanning Electron Microscopy (SEM), Confocal Laser Scanning Microscopy (CLSM) and histological analysis [33]. The SEM provides high-resolution images of debris quantity and distribution, CLSM allows three-dimensional visualization of debris and biofilm remnants [34] and histological examination provides detailed insights into debris composition [35]. In this study, red dye acrylic paint was used as a staining method to highlight debris, a technique that, while effective, has limitations compared to advanced imaging methods.

Policy Implications and Practical Recommendations

The findings of this study highlight the potential benefits of integrating TruNatomy irrigation into routine endodontic practice, particularly for cases involving curved or minimally prepared canals. However, cost-effectiveness and accessibility must be considered before recommending widespread adoption.

Compared to conventional needle irrigation, TruNatomy is a specialized system that may incur higher costs, potentially limiting its use in general dental practices. However, its advantages in apical debris removal and efficient irrigation dynamics suggest that it may be particularly beneficial in specialist endodontic clinics, where complex cases are more common.

For general dentists, conventional needle irrigation remains the most accessible and cost-effective option, but modifications such as deeper needle insertion (within 1 mm of working length) and adjunctive irrigation activation techniques (ultrasonics or negative pressure systems) could enhance irrigation effectiveness.

For specialists, particularly endodontists treating complex root anatomies, adopting TruNatomy irrigation may provide superior cleaning efficacy, reduce the risk of post-treatment complications and improve treatment success rates. Given the promising results, manufacturers should also consider cost-reduction strategies to make TruNatomy irrigation more accessible to general practitioners.

CONCLUSION

Within the limitations of this study, final irrigation with TruNatomy demonstrated significantly superior debris removal compared to conventional needle irrigation, particularly at 1 mm from the working length. These findings suggest that the TruNatomy flexible irrigation needle enhances irrigant penetration and improves debris clearance, potentially contributing to more effective endodontic disinfection and better treatment outcomes.

The clinical implications of these results are promising. TruNatomy irrigation could be beneficial in cases involving curved or minimally prepared canals, where conventional needle irrigation is less effective. However, before recommending widespread adoption, its cost-effectiveness, accessibility and long-term impact on clinical outcomes must be further explored.

Limitations

- This study was conducted using resin blocks, which provided a standardized and controlled environment for evaluating debris removal. However, resin blocks lack key anatomical characteristics of natural root canals, including apical constriction, pulp tissue presence, canal irregularities and three-dimensional curvatures. These limitations may affect the generalizability of the findings, as natural dentin permeability and tissue interactions with irrigants play a crucial role in real-world clinical scenarios
- Another limitation relates to heat generation during instrumentation, which could influence debris adhesion in artificial canals. Unlike natural teeth, which have moisture and periradicular tissues that influence debris removal, resin blocks do not accurately replicate these conditions, potentially leading to differences in irrigant distribution and debris retention
- The study also focused on single-rooted teeth with a single canal, limiting its applicability to multi-rooted teeth with complex anatomy, bifurcations, or accessory canals. Patient-specific factors such as root curvature, dentin hardness and tissue type may significantly impact the efficiency of irrigation techniques. The findings might not fully translate to cases involving calcified canals, open apices, or highly curved root morphologies, where irrigant penetration and debris removal could be more challenging
- Given these limitations, *in vivo* clinical trials are essential to validate the efficacy of the TruNatomy irrigation needle in real-world scenarios. Future research should investigate its performance in patients with varying root canal anatomies and dentin compositions, as well as assess its long-term effects on root canal healing and post-treatment prognosis

Future Research Directions

To establish stronger clinical evidence, future studies should focus on:

- *In vivo* clinical trials evaluating TruNatomy's effectiveness in real patients, particularly in complex and curved root canal systems
- Comparative studies assessing TruNatomy's performance against other advanced irrigation methods, such as ultrasonic or negative pressure irrigation systems
- Long-term follow-up studies investigating the impact of improved irrigation on root canal healing, post-operative symptoms and overall endodontic success rates

- Cost-benefit analyses to determine whether TruNatomy's improved irrigation efficiency justifies its clinical implementation in both general and specialist endodontic practice

By addressing these areas, future research can provide definitive guidance on whether TruNatomy irrigation should be integrated into routine endodontic procedures to optimize treatment outcomes.

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Ethical Considerations

This *In vitro* study did not require ethical approval; however, the authors affirm adherence to rigorous scientific and ethical standards. Transparency in research methodology has been ensured to maintain the highest integrity.

Conflict of Interest

The authors declare no conflicts of interest. The study was conducted independently, with no external influence on its design, execution, analysis, or interpretation of results.

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