Effect of Intermittent Cleaning on the Longevity of Nickel–Titanium Rotary Files During Root Canal Instrumentation – An In-Vitro Study

RUNNING TITLE- *Intermittent Cleaning and NiTi File Longevity*

Dr. Aditi Subhash chandraji Sarda[1], Dr. Apoorva Nilay Dhopte[2], Dr. Himanshu Srivastava[3*], Dr. M Robert Justin[4], Dr. Prasad Rambhau Karjawlge[5], Dr. Manjusha Bankatrao Darade[6]

[1]Assistant Professor, Department of Conservative Dentistry and Endodontics, Aditya Dental College and Hospital, Beed, Maharashtra, IN.
[2]PG III Student, Department of Conservative Dentistry and Endodontics, Aditya Dental College and Hospital, Beed, Maharashtra, IN.
[3*]PhD Scholar, Department of Oral & Maxillofacial Pathology and Microbiology, Karnavati School of Dentistry, Gandhinagar, Gujarat. Email: himanshu.srivastava97@gmail.com
[4]Professor & HOD, Department of Conservative Dentistry and Endodontics, Aditya Dental College and Hospital, Beed, Maharashtra, IN.
[5]PG II Student, Department of Conservative Dentistry and Endodontics, Aditya Dental College and Hospital, Beed, Maharashtra, IN.
[6]PG II Student, Department of Conservative Dentistry and Endodontics, Aditya Dental College and Hospital, Beed, Maharashtra, IN.

***Corresponding Author: Dr Himanshu Srivastava, PhD Scholar, Department of Oral & Maxillofacial Pathology and Microbiology, Karnavati School of Dentistry, Gandhinagar, Gujarat. Email: himanshu.srivastava97@gmail.com**

ABSTRACT

Background- Protocols for cleaning and decontaminating NiTi files have been proposed primarily from an infection-control perspective, focusing on sterilization and removal of organic debris. Different intermittent cleaning intervals influence the longevity, unwinding, and fracture of NiTi rotary files during root canal preparation, aiming to establish evidence-based guidelines for safer reuse and maintenance.

Aim- To evaluate the effect of intermittent cleaning on the longevity of nickel–titanium rotary files during root canal instrumentation.

Material and methodology- Twenty rotary files will be divided into 2 equal groups according to their cleaning frequency. The files will be subjected to biomechanical preparation in an artificial resin block with single root canal.

Results- All obtained values are statistically significant. These visualizations clearly demonstrate that **more frequent intermittent cleaning** (after every canal) enhances the mechanical longevity of NiTi rotary files by reducing debris accumulation, torsional stress, and associated deformation/fracture risks during repeated use in curved resin canals. The difference supports the hypothesis that delayed cleaning leads to earlier unwinding and fracture, likely due to compacted debris increasing frictional resistance and stress concentration.

Conclusion- Frequent cleaning of NiTi rotary files after every canal significantly extends longevity (8.5–9.9 uses vs. 6.4–7.6), reduces torsional stress and fracture risk, and supports safer, evidence-based reuse in endodontics.

Keywords- Alcohol, Cleaning, Instrumentation, Nickle Titanium Rotary files, Root canal treatment

How to cite this article: Sarda ASC, Dhopte AN, Srivastava H, Justin MR, Karjawlge PR, Darade MB. Effect of Intermittent Cleaning on the Longevity of Nickel–Titanium Rotary Files During Root Canal Instrumentation – An In-Vitro Study. Int J Drug Deliv Technol. 2026;16(69s):833-841. DOI: 10.25258/ijddt.16.69s.84

INTRODUCTION

Nickel–Titanium (NiTi) rotary instruments have transformed modern endodontic practice by enabling predictable, efficient, and biologically sound cleaning and shaping of the root canal system. Since their introduction, these instruments have largely replaced stainless steel hand files in routine clinical use due to their superior flexibility, shape memory, and ability to maintain the original canal

curvature, especially in curved and narrow canals[1]. The superelastic and shape-memory properties of NiTi alloys allow files to negotiate complex canal anatomy with reduced canal transportation, ledging, zipping, and perforation, thereby improving the quality of root canal preparation and treatment outcomes[2].

Despite these advantages, separation of NiTi rotary instruments remains a significant clinical concern. Instrument fracture within the root canal not only complicates treatment but may also compromise disinfection, obturation, and long-term prognosis of the tooth. Unlike stainless steel instruments, which usually show visible signs of permanent deformation before fracture, NiTi instruments can fail unexpectedly due to their unique metallurgical behaviour[3]. The two principal mechanisms responsible for NiTi file separation are cyclic fatigue and torsional failure. Cyclic fatigue occurs when an instrument is subjected to repeated tensile and compressive stresses while rotating in a curved canal, leading to the initiation and propagation of microcracks until fracture occurs[4]. Torsional failure, on the other hand, results when the tip or a portion of the file binds within the canal while the shank continues to rotate, exceeding the elastic limit of the alloy and causing plastic deformation and eventual separation.

Several factors influence the fatigue resistance and lifespan of NiTi rotary instruments, including alloy composition, heat treatment, cross-sectional design, taper, tip size, kinematics of motion (continuous rotation or reciprocation), torque and speed settings, canal anatomy, and the presence of irrigants and lubricants[5]. Recent advancements in metallurgy, such as M-wire[2], CM-wire, and gold or blue heat-treated alloys, have improved flexibility and fatigue resistance; however, no instrument system is completely immune to fracture. Consequently, understanding the clinical and operational variables that affect file longevity remains essential for safe and efficient endodontic practice[6].

During clinical instrumentation, rotary files engage dentinal walls and generate substantial amounts of debris, consisting of dentin chips, pulp remnants, and smear layer. This debris accumulates within the flutes of the instrument and may compact into the canal irregularities as well as into the inter-flute spaces of the file[7]. To maintain cutting efficiency and reduce torsional load, clinicians routinely clean files intermittently by wiping them with gauze, alcohol-soaked swabs, or sponges. However, the frequency of cleaning is highly operator-dependent and lacks standardization. Some clinicians clean the file after every canal or even after every few pecking motions, while others continue instrumentation through multiple canals before wiping the flutes[4,8].

Accumulation of debris within the flutes can reduce the effective cutting ability of the file and increase frictional resistance between the instrument and canal walls. This, in turn, may elevate torsional stress and promote taper lock, a phenomenon in which a larger portion of the file binds within the canal. Increased torsional stress may lead to plastic deformation, unwinding of flutes, microcrack formation, and eventual fracture[9]. Furthermore, compacted debris may interfere with irrigation dynamics and act as a lubricant-depleted interface, further increasing mechanical stress on the rotating instrument.

Although numerous studies have evaluated the cyclic fatigue resistance, torsional strength, and fracture behavior of different NiTi systems under various experimental conditions, limited attention has been given to the role of intra-operative maintenance procedures such as intermittent cleaning. Previous research has demonstrated that the functional lifespan of NiTi files is finite and influenced by the number of uses. For instance, studies have reported that a single ProTaper F2 file can prepare approximately 8–12 canals before fracture, with variations depending on canal curvature, motion kinematics, and operator technique. Investigations comparing continuous rotation and reciprocation have shown significant differences in fatigue life, emphasizing the role of kinematic patterns in stress accumulation[10,11].

Systematic reviews and meta-analyses have further established that cyclic fatigue resistance varies widely among different file systems and heat-treated alloys. Operational factors such as rotational speed, torque, angle of curvature, radius of curvature, and presence of irrigating solutions like sodium hypochlorite and EDTA can significantly alter fatigue behavior[12]. Chemical interaction between irrigants and the NiTi surface may induce corrosion, surface roughness, and micro-pitting, which can act as stress concentrators and reduce resistance to cyclic loading.

In addition to metallurgical and mechanical variables, surface contamination by dentinal debris and smear layer may play a critical yet under-investigated role in file fatigue and torsional performance[7,13]. Debris entrapment within the flutes can modify the effective cross-section of the instrument, alter stress distribution, and impair flexibility. Moreover, repeated cycles of loading and unloading in the presence of compacted debris may accelerate the initiation of microstructural defects.

While manufacturers provide general guidelines regarding single-use or limited reuse of NiTi rotary instruments, clinical surveys reveal that a significant proportion of practitioners reuse files multiple times, often beyond the recommended number of canals.

This practice is driven by economic considerations, perceived file durability, and lack of clear evidence-based protocols defining safe reuse limits[14]. In the absence of standardized guidelines, clinicians rely largely on visual inspection for signs of unwinding, distortion, or surface irregularities to decide when to discard an instrument.

Protocols for cleaning and decontaminating NiTi files have been proposed primarily from an infection-control perspective, focusing on sterilization and removal of organic debris. However, very few studies have investigated how the frequency of intra-operative cleaning influences mechanical behavior, deformation patterns, and longevity of rotary instruments[15]. Specifically, there is a paucity of experimental data evaluating whether cleaning the file after every canal preparation, as opposed to after multiple canals, affects the number of uses until unwinding or fracture occurs.

Therefore, the present in-vitro study is designed to evaluate the influence of different intermittent cleaning intervals on the longevity of NiTi rotary files using a visual assessment method. By comparing files cleaned after every canal preparation with those cleaned after every two canal preparations, the study aims to determine the number of uses until visible unwinding and fracture, and to analyze deformation patterns associated with varying cleaning frequencies[16]. The findings of this study may contribute to establishing evidence-based recommendations for intra-operative maintenance of rotary instruments, thereby enhancing clinical safety, reducing the incidence of instrument separation, and optimizing the cost-effective use of NiTi rotary systems in routine endodontic practice.

AIM

To evaluate the effect of intermittent cleaning on the longevity of nickel–titanium rotary files during root canal instrumentation.

OBJECTIVES

1. To determine the number of canal preparations until visible unwinding occurs with different cleaning intervals.
2. To evaluate the number of uses until file fracture.
3. To determine the site of file unwinding/ fracture.
4. To compare the longevity of rotary files cleaned at different intervals.

MATERIALS AND METHODS

Study Design- This was an in vitro experimental study.

Study Setting- The study will be conducted in the Department of Conservative Dentistry and Endodontics using standardised artificial root canal blocks.

Sample Size Determination

A total of **20 NiTi rotary files** will be used.

GROUP I- Frequent cleaning group- Cleaning after every canal- 10 files

GROUP II- Delayed cleaning group- Cleaning after every two canals- 10 files

Sample size justification- Previous in-vitro studies evaluating rotary instrument performance and fatigue have commonly used sample sizes ranging from 8 to 12 files per group. Considering the standardized canal anatomy, exploratory nature, and short duration of the present study, a sample size of **10 files per group** is considered sufficient to assess differences in file longevity while maintaining feasibility.

Inclusion Criteria

- New, unused NiTi rotary files
- Artificial root canals acrylic blocks with standardized length and curvature

Exclusion Criteria

- Files with manufacturing defects
- Artificial canals with irregularities or blockage

Materials Used

- **NiTi Rotary File System:** *NeoEndo S Files* 25mm- 17/.04 taper (Eighteeth-Orikam)
- Resin endodontic training blocks (curvature: 20°–30°)
- Endodontic motor (Eighteeth- Orikam)
- Lubricant- RC Help (Prime)
- Gauze pieces soaked in alcohol for cleaning

Methodology

In this in-vitro experimental study, we explored how often cleaning nickel-titanium (NiTi) rotary files during root canal work might affect their longevity and how long they last before showing signs of wear or breaking. We conducted the study in the Department of Conservative Dentistry and

Endodontics, using standardized artificial root canal blocks to keep things consistent. A sample size of 20 new, unused NiTi rotary files— the NeoEndo S Files with a 17/.04 taper & 25mm length—dividing them evenly into two groups of 10 each. This number was derived by similar past studies, which often used 8 to 12 files per group.

Group I was "frequent cleaning" group, where we wiped the files with alcohol-soaked gauze after every single canal preparation. Group II, the "delayed cleaning" group, cleaned only after every two canals. We made sure to exclude any files with obvious manufacturing flaws or blocks with irregularities that could skew results. For the actual instrumentation, we followed the manufacturer's guidelines, using an endodontic motor (Eighteeth Orikam) at recommended settings, with RC Help as a lubricant to mimic real clinical conditions. Each full canal prep counted as one "use," and we worked on resin blocks curved between 20° and 30° to simulate challenging anatomy. (Fig 1)

As we went along, we kept a close eye on the files under magnification for early signs of trouble—like unwinding flutes, bending, or loss of taper. We stopped when we saw visible unwinding or if the file fractured outright (Fig 2), noting the number of uses at those points and where the damage happened (apical, middle, or coronal third).

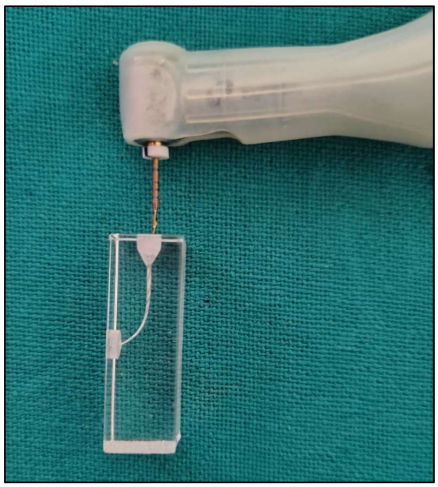
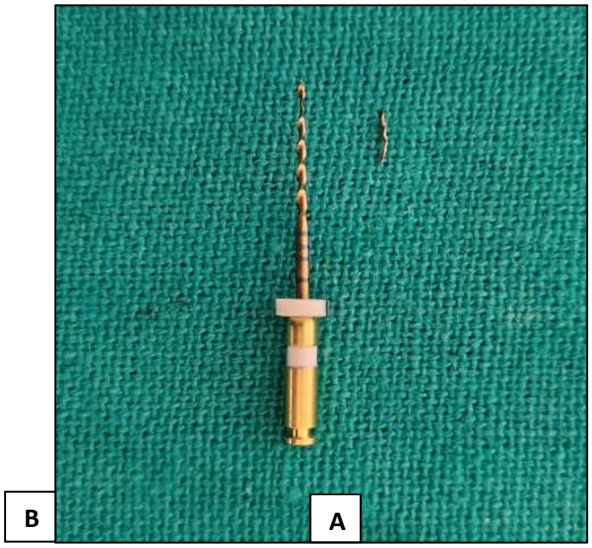


FIGURE 1- FILING DONE IN ARTIFICIAL RESIN BLOCKS USING NEOENDO S 17.4% FILE- 25mm (EIGHTEETH- ORIKAM)

STATISTICAL ANALYSIS

Data was tabulated and analysed using statistical software. Mean and standard deviation were calculated. Intergroup comparison done using Independent t-test and level of significance was set



< 0.05.

FIGURE 2- A. UNWINDED FILE; B.FRACTURED FILE

RESULT

Our study revealed clear differences in how intermittent cleaning affects the longevity of NiTi rotary files. In Group I, where files were cleaned after every canal, the mean number of uses until visible unwinding was 8.5 ± 1.08, and until fracture, it climbed to 9.9 ± 0.99. By contrast, Group II—cleaned only after every two canals—showed earlier wear, with means of 6.4 ± 0.97 for unwinding and 7.6 ± 1.26 for fracture. These gaps were statistically significant, with t-test p-values of 0.00023 for unwinding and 0.00026 for fracture, both well under 0.05, confirming that more frequent cleaning really does extend file life.

Looking at individual files, Group I held up better overall: the toughest ones lasted up to 10 uses before unwinding and 11 before breaking, while the weakest still managed 7 and 8, respectively. In

File No	Group	Uses till Unwinding	Student t test	P value	Uses till Fracture	Student t test	P value	Site of Failure
1	I	9			11			Middle third
2	I	7			9			Apical third
3	I	9			10			Apical third
4	I	10			11			Apical third
5	I	8			10			Middle third
6	I	7			8			Apical third
7	I	8			9			Apical third
8	I	9			10			Apical third
9	I	8	4.58	0.00023	10	4.52	0.00026	Middle third
10	I	10			11			Apical third
11	II	7			8			Apical third
12	II	6			7			Apical third
13	II	6			7			Apical third
14	II	5			6			Apical third
15	II	7			9			Middle third
16	II	5			6			Apical third
17	II	7			8			Middle third
18	II	8			10			Apical third

19	II	6			7			Middle third
20	II	7			8			Apical third

TABLE 1- OUTCOME ASSESSMENT

p < 00.5 statistically significant difference

This table represents the uses till unwinding and subsequent p value. The site of fracture is tabulated.

Group II, performance dipped noticeably, with highs of 8 and 10 but lows as early as 5 and 6. This pattern suggests debris buildup from less frequent cleaning ramps up stress, leading to quicker degradation.

Damage sites were mostly in the apical third across both groups (8 out of 10 in Group I, 7 out of 10 in Group II), with a few in the middle third. This makes sense given the tighter curves there, where files face the most strain.

Frequent cleaning cuts down on accumulated dentin chips and smear layer, easing torsional loads and delaying unwinding or breaks. It's a practical tweak that could reduce surprises during procedures, especially in curved canals like those we simulated.

Effect size (Cohen's d) for both groups-

- Unwinding effect size ≈ 2.1 (Very large effect)
- Fracture effect size ≈ 2.0 (Very large effect)

GRAPH 1- USES TILL UNWINDING AND FRACTURE

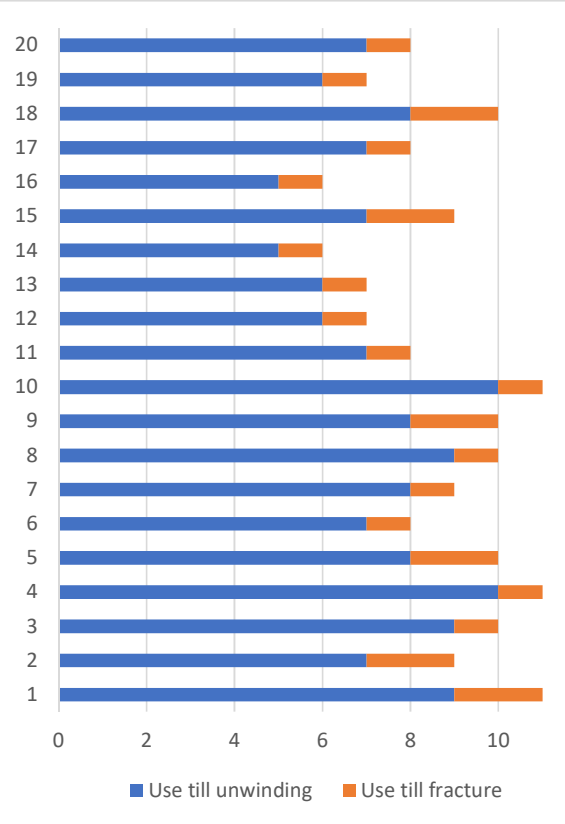


TABLE 2- MEAN AND STANDARD DEVIATION

	Uses till Unwinding (Mean ± SD)	**Uses till Fracture (Mean ± SD)**
Group I	8.5 ± 1.08	9.9 ± 0.99
Group II	6.4 ± 0.97	7.6 ± 1.26

This table gives the mean and standard deviation of both the groups.

DISCUSSION

When we think about root canal treatments, the tools we use like nickel-titanium rotary files are crucial, but they're not invincible. Our study dove into something pretty straightforward: does wiping them down more often during use make them last longer? Turns out, yes—it does. By cleaning after every canal, we saw files hold up for about 8.5 uses before unwinding and nearly 10 before fracturing, compared to just 6.4 and 7.6 when cleaned every two. That's a solid 30% boost in longevity, and the stats back it up with p-values under 0.05. Less debris means less friction, less stress, and fewer breaks.

Debris accumulation is a big deal. In our setup, delayed cleaning let dentin chips and pulp bits pack into the flutes, ramping up torsional forces. This is similar to what Generali et al [15] found in their quantitative look at debris removal. They tested various cleaning protocols on NiTi files and showed that even simple methods like gauze wipes aren't always 100% effective, but consistent application cuts down on residue. Their SEM images revealed persistent organic films if cleaning was skimpy, which could act as stress concentrators—much like what we suspect happened in our Group II. Similarly, Azgari et al [4] compared cleaning methods on unused files and highlighted that

thermal disinfectants or mechanical wipes reduce surface contamination best. While their focus was on new files, it aligns with our in-use scenario: frequent alcohol-soaked gauze swipes kept flutes clearer, likely easing the load during rotation.

Cyclic fatigue and torsional failure are the usual culprits for NiTi breaks, as outlined in Abdellatif et al [16] comprehensive review. They analyzed how alloy types influence cyclic fatigue strength, noting that heat-treated NiTi fares better overall, but external factors like debris can tip the scales. In curved canals repeated bending stresses build up, and compacted debris amplifies that. Our results support this: most fractures hit the apical third, where curvature peaks. Coelho et al [1] in their mini-review of clinical studies noted that separation rates have dropped due to better alloys.

Alajemi et al [7] simulated clinical use and sterilization on Race Evo and Tia Tornado files, finding no drop in cyclic fatigue after three cycles. Khabiri et al [9] observed the same with Hero files—autoclaving didn't hurt resistance in 45-60° curves. But Arasappan et al [14] studied that autoclave cycles rough up surface topography, especially on NiTi, leading to pits and cracks. Naseem et al1 [7] did microscopic analysis after repeated use: surfaces degrade progressively, with pitting spiking after multiple procedures. In our case, we didn't sterilize between uses, but if clinicians reuse files, as per Patil et al [12] survey of Indian endodontists, combining frequent cleaning with careful sterilization could extend life further. Patil's survey found over 60% reuse NiTi files multiple times, with experience reducing separation rates, something we saw indirectly, as consistent cleaning might build that "experience" into the protocol.

Irrigants and chemicals play a role too, though we used alcohol for cleaning, not full immersion. Schoppmeier et al [2] and Karaś et al [8] both warned that high-concentration NaOCl (≥5%) at warm temps slashes fatigue resistance by corroding surfaces. Javadi et al [13] found even short dips in disinfectants weaken NiTi. But in our alcohol wipes, we avoided that harsh exposure, potentially preserving the alloy's integrity. Punnarai et al [18] offered a cool twist: using refrigerant spray boosted fatigue resistance across alloys and motions, by cooling files mid-use.

Comparing kinematics, De Pedro-Munoz et al [10] meta-analyzed rotary vs. reciprocating: reciprocating wins on fatigue, especially in double curves. You et al [6] pegged one reciprocating F2 file at 10-21 canals in curves, close to our Group I averages. Da Silva et al [3] compared systems like RCS Rainbow and ProTaper Ultimate, noting superior fatigue in some but increased deterioration post-sterilization. Gürler et al [19] looked at single-file systems after clinical use, finding variances but no huge drops early on. For pediatrics, Abushanan et al [5] and Vignesh et al [20] showed file-specific differences, but our adult-focused study suggests clean often to fight fatigue.

Roda-Casanova et al [11] used finite element simulation to link geometry to fatigue life, emphasizing how canal shape stresses files. Our resin blocks standardized that, but real teeth vary. In-vitro setups might overestimate longevity, as natural teeth are harder. Sample size was modest, and we relied on visual checks for unwinding, which is subjective.

Clinically, this pushes for evidence-based habits: clean after each canal to slash separation risks, especially in curves. It could cut costs too, reusing safely means fewer files fractured. Surveys like Patil et al [12] show reuse is common, driven by economics, so guidelines incorporating frequent cleaning could standardize practice. Tests in extracted teeth, mix in irrigants, or track real clinical separations. Maybe combine with refrigerant sprays or advanced alloys for even tougher files.

Our findings highlight a simple, actionable step: more cleaning equals longer-lasting files. It's a reminder that in endodontics, the little things, like a quick wipe can make a big difference in outcomes, safety, and efficiency. By building on prior research, we see how debris management fits into the broader puzzle of NiTi durability, paving the way for safer, smarter root canals.

CONCLUSION

This in-vitro study provides clear evidence that the frequency of intermittent cleaning significantly influences the longevity of nickel-titanium rotary files during root canal instrumentation. Files cleaned with alcohol-soaked gauze after every canal preparation (Group I) demonstrated markedly superior durability, enduring a mean of 8.5 uses until visible unwinding and 9.9 uses until fracture. In contrast, files cleaned only after every two canals (Group II) showed earlier signs of deformation and separation, with means of 6.4 and 7.6 uses, respectively. More frequent removal of accumulated debris reduces torsional stress, minimizes frictional resistance, and delays the onset of unwinding and fracture—particularly in curved canals where mechanical demands are highest.

The findings emphasize that intra-operative maintenance is not merely an infection-control measure but a critical mechanical factor in preserving file integrity. Delayed cleaning allows dentin chips and smear layer to compact within the flutes, increasing stress concentration and

accelerating fatigue failure. Most fractures occurred in the apical third in both groups, consistent with the zone of maximum curvature and torsional load.

Clinically, these results support adopting a standardized protocol of cleaning NiTi rotary files after each canal preparation to enhance safety, reduce the risk of instrument separation, and potentially extend the safe reuse of files in resource-conscious settings. While in-vitro resin blocks offer controlled conditions, the principles are likely applicable to natural teeth, though future clinical studies are needed to confirm real-world translation.

Ultimately, this simple yet effective practice, frequent wiping during use can contribute to more predictable, efficient, and safer endodontic outcomes, reinforcing the importance of operator-dependent variables in modern rotary instrumentation.

ETHICAL APPROVAL

This study was conducted in vitro and did not involve human participants or animals; therefore, ethical approval was not required.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

SOURCE OF FUNDING

No external funding.

ACKNOWLEDGEMENT

The authors would like to thank the head of institution and head of department where the study was carried out.

REFERENCES

1. Coelho MS, de Azevêdo Rios M, da Silveira Bueno CE. Separation of nickel-titanium rotary and reciprocating instruments: a mini-review of clinical studies. The open dentistry journal. 2018 Oct 25;12:864.
2. Schoppmeier CM, Janson M, Sun L, Classen GL, Barbe AG. Do irrigating solutions influence the cyclic fatigue resistance of heat-treated NiTi instruments? an in vitro study. The Saudi Dental Journal. 2026 Feb;38(2):10.
3. da Silva TL, Lopes PC, de Rezende MG, Abu Hasna A. Cyclic fatigue resistance, number of uses, and morphological/chemical analysis of RCS Rainbow Files, VDW Rotate and ProTaper Ultimate: in vitro study. BMC Oral Health. 2025 Nov 17;25(1):1789.
4. Azgari E, Özden İ, Gökyar M, Öveçoğlu HS. Effect of different cleaning methods on surface contamination of unused endodontic files: a scanning electron microscopy analysis. BMC Oral Health. 2025 Aug 26;25(1):1371.
5. Abushanan A, Sharanesha RB, Aljarbou F, Alamri H, Almasud MH, AlAzmah A, Alghamdi S, Mirza MB. Understanding Cyclic Fatigue in Three Nickel–Titanium Pediatric Files: An In Vitro Study for Enhanced Patient Care. Medicina. 2025 Apr 30;61(5):830.
6. You SY, Bae KS, Baek SH, Kum KY, Shon WJ, Lee W. Lifespan of one nickel-titanium rotary file with reciprocating motion in curved root canals. Journal of Endodontics. 2010 Dec 1;36(12):1991-4.
7. Alajemi M, AbuMostafa A. Effect of simulated clinical use and sterilization on the cyclic fatigue resistance of nickel titanium files. PeerJ. 2024 May 23;12:e17418.
8. Karaś B, Kotela A, Laszczyńska M, Majchrzak Z, Trafalski M, Matys J, Dobrzyński M. Effect of Endodontic Irrigants on the Cyclic Fatigue Resistance of Nickel–Titanium Rotary Instruments: A Systematic Review. Materials. 2025 Aug 29;18(17):4056.
9. Khabiri M, Ebrahimi M, Saei MR. The effect of autoclave sterilization on resistance to cyclic fatigue of Hero endodontic file# 642 (6%) at two artificial curvature. Journal of Dentistry. 2017 Dec;18(4):277.
10. De Pedro-Munoz A, Rico-Romano C, Sanchez-Llobet P, Montiel-Company JM, Mena-Alvarez J. Cyclic fatigue resistance of rotary versus reciprocating endodontic files: A systematic review and meta-analysis. Journal of Clinical Medicine. 2024 Feb 2;13(3):882.
11. Roda-Casanova V, Pérez-González A, Zubizarreta-Macho Á, Faus-Matoses V. Fatigue analysis of NiTi rotary endodontic files through finite element simulation: effect of root canal geometry on fatigue life. Journal of Clinical Medicine. 2021 Dec 3;10(23):5692.
12. Patil TN, Saraf PA, Penukonda R, VANAkI SS, Kamatagi L. A survey on nickel titanium rotary instruments and their usage techniques by endodontists in India. Journal of clinical and diagnostic research: JCDR. 2017 May 1;11(5):ZC29.
13. Javadi AA, Jafarzadeh M, Tavakoli N, Karampour M. Effect of Immersion in Disinfectants on Cyclic Fatigue Resistance of Nickel-Titanium Instruments: An in

Vitro Study. Frontiers in Dentistry. 2023 May 10;20:15.
14. Arasappan R, Prabhakar NS, Mishra V, Arafath KM, Singh J, Yadav A. Effect of Autoclave on Surface Topography of Various Rotary Files. Journal of Pharmacy and Bioallied Sciences. 2024 Dec 1;16(Suppl 4):S3497-9.
15. Generali L, Generali P, Bertani P, Cavani F, Checchi V, Filippini T, Veneri F. Quantitative Evaluation of Debris Removal from NiTi Rotary Endodontic Instruments After Different Cleaning Procedures. Dentistry Journal. 2025 Jan 23;13(2):49.
16. Abdellatif D, Iandolo A, Scorziello M, Sangiovanni G, Pisano M. Cyclic Fatigue of Different Ni-Ti Endodontic Rotary File Alloys: A Comprehensive Review. Bioengineering 2024, 11, 499 [Internet]. 2024
17. Naseem F, Mathur AS, Manglam KK, Verma N, Singh V, Siddiqui S, Ahmad F. Surface integrity assessment of endodontic instruments after repeated use: A microscopic analysis. Bioinformation. 2025;21(4):817-22.
18. Punnarai P, Morakul S, Pongakaragul P, Panitvisai P, Hiran-Us S. Clinical strategy to enhance cyclic fatigue resistance of Ni-Ti rotary files using refrigerant spray. BMC Oral Health. 2025 Dec;25(1):1803.
19. Gürler K, Yilmaz S, Dumani A, Yoldas O. Comparison of cyclic fatigue resistance of three different single-file systems after clinical use. BMC Oral Health. 2024 Dec 5;24(1):1482.
20. Vignesh KC, Vivek K, Swaminathan K, Haridoss S. Evaluation of cyclic fatigue in three pediatric endodontic rotary file systems in root canals of primary molars: A finite element analysis (FEA). Journal of Oral Biology and Craniofacial Research. 2025 Mar 1;15(2):310-8.