applied sciences

*Editorial*

# Are the Current Research Methods Reliable for Evaluating the Mechanical Performance of NiTi Endodontic Rotary Instruments?

**Franco Maria Di Russo [1], Annamaria Gisario [1], Stefano Natali [2], Valentina Bellanova [3], Chiara Leone [3] and Luca Testarelli [3,*]**

[1] Department of Mechanical and Aerospace Engineering, Sapienza University of Rome, 00185 Rome, Italy
[2] Department of Chemical Engineering, Materials and Environment, Sapienza University of Rome, 00185 Rome, Italy
[3] Department of Oral and Maxillo-Facial Sciences, Sapienza University of Rome, Via Caserta 06, 00161 Rome, Italy
* Correspondence: luca.testarelli@uniroma1.it

**Citation:** Di Russo, F.M.; Gisario, A.; Natali, S.; Bellanova, V.; Leone, C.; Testarelli, L. Are the Current Research Methods Reliable for Evaluating the Mechanical Performance of NiTi Endodontic Rotary Instruments? *Appl. Sci.* **2022**, *12*, 11378. https://doi.org/10.3390/app122211378

Received: 9 October 2022
Accepted: 4 November 2022
Published: 9 November 2022

Technological innovation and the modernization of manufacturing procedures have thoroughly redefined the field of nickel–titanium (NiTi) rotary and reciprocating endodontic instruments [1]. In fact, in recent decades, several advances have been introduced both in terms of design and NiTi alloy treatments, such as superficial and heat treatments [2]. Design and metallurgical improvements proposed by factories and manufacturers have the scope to directly enhance the mechanical performance of NiTi instruments, such as their flexibility, cyclic fatigue and torsional resistances, and cutting efficiency, not only reducing the possibility of intracanal failure as much as possible, but also increasing their user-friendliness, facilitating their cutting action and progression inside canals, and minimizing the respective risks [3,4].

Despite this, experimental setups and testing methodologies have not kept abreast with those exponential developments, resulting in an alarming discrepancy—in terms of the avant-garde—between current official testing specifications and innovations in endodontic NiTi instruments. In fact, as stated by Schafer et al., neither ANSI/ADA (American Dental Standard/American Dental Association) nor ISO (International Organization for Standardization) specifications adequately consider the modified properties of recent generations of NiTi instruments. As a matter of fact, those international specifications have been stipulated to not consider the actual mechanical loads, both in terms of flexural and torsional stresses, acting on instruments during root canal shaping, resulting in misleading results that do not reflect the use of the instruments under clinical conditions [5].

The mechanical performance of NiTi endodontic instruments is usually investigated with the use of five principal tests: fatigue tests, torsional and angular deflection tests, bending or flexibility tests, and cutting efficiency evaluations [3,5–7].

Cyclic fatigue arises from continuous compression and tension strain cycles at the inner and outer curvatures depending on several factors, such as the rotational speed, angle, and radius of the curvature, temperature, metal mass, and, thus, cross-sectional design, tip diameter, taper, and number of threads [5]. The most common test used to evaluate the cyclic fatigue of NiTi instruments is characterized by the static rotation at a prestabilized speed and torque limit inside an artificial canal with a determined angle and radius of curvature [2]. The instrument can be actioned and the number of cycles to fracture (NCF) and/or time to fracture (seconds) can be recorded. These research methods are described by the currently available ANSI/ADA and ISO specifications, although manual stainless-steel files are stipulated to have been taken as the reference, thus, actually, resulting in them not being suited for assessing the fracture properties of modern NiTi instruments. First of all, the above-mentioned specifications do not take into account the temperature at which the test should be performed, whether it be at room or body temperature, since it has been demonstrated previously that variations in temperature are capable of significantly influencing the outcome of fatigue tests [8–10]. Despite this, the influence of the intracanal temperature on the mechanical performance of NiTi instruments during clinical practice is still controversial, requiring further in vivo and ex vivo experiments. Another issue regarding current fatigue tests is the use of irrigants. Apparently, the use of a lubricant is associated with an increase in terms of the NCF and, second, during cyclic fatigue testing; despite this, several fluids have been used as lubricants and more precise specifications should be drawn [5]. The last concern about current fatigue tests is the dimension of the artificial canals. As suggested by several authors, an optimal match between the canal and the instrument, with a low grade of tolerance, ensures testing without friction and frictional heat [11,12].

According to the result of fatigue tests present in the literature, cyclic fatigue does not seem to play a significant role in clinical situations, because both the NCF and time to fracture are generally significantly higher than the time needed for root canal preparation. Despite this, fatigue failure occurs, and this is probably due to the interaction between torsional and flexural stresses during root canal preparation [13,14]. For this reason, further experimental methods should be developed with the aim of simultaneously evaluating the reciprocal influence between those two factors.

Regarding torsional loads, the most common static test (also recommended by the ISO specification 3630-1:2019) consists of the rotation of the instrument at 2 rpm and then blocking its tip at 3 mm with a metal vice. Then, the torque at fracture and angular deflection are calculated and analyzed [5]. Despite the specifications requiring a precise rotational speed, some authors stated that the rotational speed does not influence the torque to fracture (TtF) of NiTi endodontic instruments [15]. Furthermore, the actual role of maximum torsional loads being withstood by endodontic instruments should be clarified. Even in this case, the above-mentioned specifications did not describe the temperature at which the test should be performed; thus, further clarification on this theme is needed. In several articles comparing austenitic and martensitic instruments, the results showed no significant statistical differences in terms of the TtF, despite the relevant difference in the metallurgical properties of the two crystallographic phases [1,3,16]. This is due to the different plastic and elastic behaviors of austenite and martensite, with an increased plasticity of the latter, resulting in an increased angular deflection. According to this, TtF values should be accompanied by torque values, at which plastic (irreversible) deformation occurs, in order to provide clinically significant data, since a deformed or despiralized instrument should no longer be used.

The bending and flexibility properties of instruments are evaluated with static tests that do not consider the rotational moment or stress, due to their contact with the root canal walls. For these reasons, the actual clinical relevance of these tests is poor, and bending data alone do not give clinicians any specific information [5].

As thoroughly demonstrated in the literature, the cutting ability of endodontic instruments is guaranteed due to several instrument-related parameters, such as the cross-sectional design, chip removal capacity, rake and helix angles, metallurgical properties, surface hardness, and treatments. Furthermore, its efficiency is also related to instrumentation strategies, such as the rotational speed, motions, feed rate, and apical pressure [5]. Additionally, those factors are difficult to isolate and singularly evaluate; thus, experimental methods should guarantee a precise evaluation of their reciprocal interactions. Probably for this reason, to date, standards and specifications have not been established for the evaluation of the cutting efficiency of root canal instruments. According to this, several methodologies have been proposed, such as lateral cutting, axial action, or ones considering the time required to perform the shaping procedures and different parameters. They were considered as a result of the cutting action, such as the weight loss of the substrate, the measurement of resulting grooves on the substrate, and microcomputer tomography for evaluating the differences in terms of the initial and final intracanal volume (shaping ability) [5]. Obviously, those differences in terms of methodologies cause a lack of standardization in scientific data, resulting in an impossible comparison between studies. According to this, specifications are fundamental.

In conclusion, static tests have provided a large amount of information regarding the influence of specific parameters on the mechanical performance of endodontic NiTi instruments. Despite this, their actual behavior during clinical practice cannot be fully described, resulting in a low power of significance. According to this, several authors proposed some dynamic tests in order to obtain reliable data able to explain the stresses acting on instruments during in vivo root canal shaping [17–20]. Nevertheless, the lack of standardization in dynamic tests contributed a plethora of experimental methods, not directly comparable to one another.

**Author Contributions:** Conceptualization, L.T.; validation, S.N. and C.L.; writing—original draft preparation, F.M.D.R. and A.G.; writing—review and editing, V.B.; supervision, L.T. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## References

1. Zupanc, J.; Vahdat-Pajouh, N.; Schäfer, E. New thermomechanically treated NiTi alloys-a review. *Int. Endod. J.* **2018**, *51*, 1088–1103. https://doi.org/10.1111/iej.12924.
2. Hülsmann, M.; Donnermeyer, D.; Schäfer, E. A critical appraisal of studies on cyclic fatigue resistance of engine-driven endodontic instruments. *Int. Endod. J.* **2019**, *52*, 1427–1445. https://doi.org/10.1111/iej.13182.
3. Zanza, A.; D'Angelo, M.; Reda, R.; Gambarini, G.; Testarelli, L.; Di Nardo, D. An Update on Nickel-Titanium Rotary Instruments in Endodontics: Mechanical Characteristics, Testing and Future Perspective-An Overview. *Bioengineering* **2021**, *8*, 218. https://doi.org/10.3390/bioengineering8120218.
4. Zanza, A.; Seracchiani, M.; Reda, R.; Miccoli, G.; Testarelli, L.; Di Nardo, D. Metallurgical Tests in Endodontics: A Narrative Review. *Bioengineering* **2022**, *9*, 30. https://doi.org/10.3390/bioengineering9010030.
5. Schäfer, E.; Bürklein, S.; Donnermeyer, D. A critical analysis of research methods and experimental models to study the physical properties of NiTi instruments and their fracture characteristics. *Int. Endod. J.* **2022**, *55*, 72–94. https://doi.org/10.1111/iej.13673.
6. Seracchiani, M.; Donfrancesco, O.; Relucenti, M.; Reda, R.; Zanza, A.; Gambarini, G.; Testarelli, L. In vitro evaluation of a recently developed rotary file: Af rotary. *Braz. Dent. Sci.* **2021**, *24*, 4. https://doi.org/10.14295/bds.2021.v24i4.2558.
7. Seracchiani, M.; Reda, R.; Zanza, A.; D'Angelo, M.; Russo, P.; Luca, T. Mechanical Performance and Metallurgical Characteristics of 5 Different Single-file Reciprocating Instruments: A Comparative In Vitro and Laboratory Study. *J. Endod.* **2022**, *48*, 1073–1080. https://doi.org/10.1016/j.joen.2022.05.009.
8. Dosanjh, A.; Paurazas, S.; Askar, M. The Effect of Temperature on Cyclic Fatigue of Nickel-titanium Rotary Endodontic Instruments. *J. Endod.* **2017**, *43*, 823–826. https://doi.org/10.1016/j.joen.2016.12.026.
9. Alfawaz, H.; Alqedairi, A.; Alsharekh, H.; Almuzaini, E.; Alzahrani, S.; Jamleh, A. Effects of Sodium Hypochlorite Concentration and Temperature on the Cyclic Fatigue Resistance of Heat-treated Nickel-titanium Rotary Instruments. *J. Endod.* **2018**, *44*, 1563–1566. https://doi.org/10.1016/j.joen.2018.07.009.
10. Staffoli, S.; Grande, N.M.; Plotino, G.; Özyürek, T.; Gündoğar, M.; Fortunato, L.; Polimeni, A. Influence of environmental temperature, heat-treatment and design on the cyclic fatigue resistance of three generations of a single-file nickel-titanium rotary instrument. *Odontology* **2019**, *107*, 301–307. https://doi.org/10.1007/s10266-018-0399-5.
11. Bürklein, S.; Maßmann, P.; Donnermeyer, D.; Tegtmeyer, K.; Schäfer, E. Need for Standardization: Influence of Artificial Canal Size on Cyclic Fatigue Tests of Endodontic Instruments. *Appl. Sci.* **2021**, *11*, 4950; https://doi.org/10.3390/app11114950.
12. Zanza, A.; Russo, P.; Di Matteo, P.; Reda, R.; Di Nardo, D.; Gambarini, G.; Testarelli, L. Mechanical properties and metallurgical features of two similar endodontic rotary instruments with different heat treatments (FireWire™ and Gold). *Sci. Prog.* **2022**, *105*, 368504221103763. https://doi.org/10.1177/00368504221103763.

13. Seracchiani, M.; Miccoli, G.; Di Nardo, D.; Zanza, A.; Cantore, M.; Gambarini, G.; Testarelli, L. Effect of Flexural Stress on Torsional Resistance of NiTi Instruments. *J. Endod.* **2021**, *47*, 472–476. https://doi.org/10.1016/j.joen.2020.10.011.
14. Di Nardo, D.; Zanza, A.; Seracchiani, M.; Donfrancesco, O.; Gambarini, G.; Testarelli, L. Angle of Insertion and Torsional Resistance of Nickel–Titanium Rotary Instruments. *Materials* **2021**, *14*, 3744. https://doi.org/10.3390/ma14133744.
15. Ha, J.H.; Kwak, S.W.; Kim, S.K.; Sigurdsson, A.; Kim, H.C. Effect from Rotational Speed on Torsional Resistance of the Nickel-titanium Instruments. *J. Endod.* **2017**, *43*, 443–446. https://doi.org/10.1016/j.joen.2016.10.032.
16. Zanza, A.; Seracchiani, M.; Reda, R.; Di Nardo, D.; Gambarini, G.; Testarelli, L. Role of the Crystallographic Phase of NiTi Rotary Instruments in Determining Their Torsional Resistance during Different Bending Conditions. *Materials* **2021**, *14*, 6324. https://doi.org/10.3390/ma14216324.
17. Li, U.M.; Lee, B.S.; Shih, C.T.; Lan, W.H.; Lin, C.P. Cyclic fatigue of endodontic nickel titanium rotary instruments: Static and dynamic tests. *J. Endod.* **2002**, *28*, 448–451. https://doi.org/10.1097/00004770-200206000-00007.
18. Peters, O.A.; Barbakow, F. Dynamic torque and apical forces of ProFile.04 rotary instruments during preparation of curved canals. *Int. Endod. J.* **2002**, *35*, 379–389. https://doi.org/10.1046/j.0143-2885.2001.00494.x.
19. De-Deus, G.; Leal Vieira, V.T.; Nogueira da Silva, E.J.; Lopes, H.; Elias, C.N.; Moreira, E.J. Bending resistance and dynamic and static cyclic fatigue life of Reciproc and WaveOne large instruments. *J. Endod.* **2014**, *40*, 575–579. https://doi.org/10.1016/j.joen.2013.10.013.
20. Tokita, D.; Ebihara, A.; Nishijo, M.; Miyara, K.; Okiji, T. Dynamic Torque and Vertical Force Analysis during Nickel-titanium Rotary Root Canal Preparation with Different Modes of Reciprocal Rotation. *J. Endod.* **2017**, *43*, 1706–1710. https://doi.org/10.1016/j.joen.2017.05.010.