Sumerianz Journal of Scientific Research, 2018, Vol. 1, No. 4, pp. 88-94
ISSN(e): 2617-6955, ISSN(p): 2617-765X
Website: https://www.sumerianz.com

Original Article Open Access

Fracture Resistance for Fatigue Cyclical Nickel - Titanium Endodontic Instruments – Literature Review

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Abstract

Background: rotary endodontic instrument fractures have been related as a major problem in Endodontics due to the complications that follow such incidents. Objective: The aim of this review was to evaluate, through traditional literature review, the factors that influence fracture resistance of endodontic NiTi instruments used in mechanical preparation and shaping of the root canals. Methods: The review was made by two independent reviewers and the following electronic databases were used: PUBMED Central, BVS/BIREME, Web of Science, Science Direct, Higher Level Personnel Improvement Coordinator (CAPES) Periodic Portal , The Cochrane Library and PROSPERO, from 1988 to 2014.Results: the number of cycles to which rotary NiTi instruments have been submitted showed that fracture resistance is directly related to fracture resistance; composition and thermomechanical processing of the alloy and transverse cross sections and dimensions. Conclusions: Fracture resistance seems to be related to the number of cycles that an instrument is able to resist after a given load conditions. Kinematic motion, alloy composition, different rotational angles and the speed used, as well as the shape and area of the cross section of the straight instrument, are the main fracture causes.
Keywords: Endodontics; Dental instruments; Root canal preparation; Titanium; Nickel.

1. Introduction

In recent years, since the presentation of nickel-titanium (NiTi) instruments and rotary engines, profound changes have been observed in relation to the shaping and mechanical root canal preparation. when compared to traditional stainless steel instruments, mainly due to peculiar characteristics such as flexibility [1], superior cuttability [2], better maintenance of the original canal shape, thus reducing the transport of debris and microorganisms to the foramen [3]; [4], as well as the operative time [4]. However; despite its proven benefits, these instruments many times undergo premature failures such as bending, torsion or cyclic fatigue. Such a disadvantage often reflects on rejection by endodontists, who claim for improvements necessary for such technological devices.

The flexibility of mechanized NiTi instruments is influenced by metallurgical properties (composition and thermomechanical processing of the alloy) along with their geometric characteristics, like transverse cross sections and dimensions [5]; [6]. Their increased flexibility is achieved either by changes in design characteristics (different variations of the form of transverse straight sections thereof), or by the type of NiTi alloy [7]; [6] The cyclic fatigue fracture occurs as a result of the continuous rotation of the instrument in a curved root canal space. In this condition, the instrument, under elastic deformation, is subjected to a mechanical load tensile and compressive stress every time it is used. Thus, the fatigue resistance comprising the number of cycles that the tool can withstand under specific

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load condition will determine the existence of fractures [8]. As NiTi instruments do not clearly show visible signs of permanent deformation during the fatigue test, the fracture may occur unexpectedly.

In order to improve the fracture resistance and flexibility of NiTi rotary instruments, researchers and manufacturers have developed new methods. One of them has produced the M-wire nickel-titanium alloy, developed using a novel thermomechanical treatment process [9]. Its benefits are increased flexibility of the file and increased resistance to cyclic fatigue caused by tension forces and file compression [10]; [11].

A new perspective on NiTi files was made by Yared in 2008, by reciprocation or reciprocal motion using a single F2 ProTaper file (Dentsply, Mailefer, Switzerland). From this initial research, several studies were conducted and concluded that the reciprocating movement would have major advantages over conventional rotary movements, reducing file stress, particularly in curved canals due to its kinematics (counterclockwise cutting direction and then a clockwise release direction of movement of the instrument). Such movement seems to reduce the risk of cyclic fatigue of the instrument [12].

Constant efforts are being made in search of the ideal instrument with properties and characteristics in order to overcome the anatomical interferences offered by the peculiarities of root canals. Therefore, the aim of this review was to evaluate, through a traditional literature review, the fatigue fracture resistance of endodontic NiTi instruments used in mechanical preparation and shaping of the root canals.

2. Literature Review

AL-Hadlaq, *et al.* [10] investigated the resistance to flex fatigue rotary endodontic instruments made of NiTi M-Wire alloy (GTX), compared with the ones made of conventional alloy, represented by Profile in this study .The laboratory tests suggested that the rotary files made of Wire-M alloy showed better fatigue resistance than those made of conventional alloy, since the particular thermal process by which it is made contributes to the increased flexibility and resistance of the instruments.

Wan, *et al.* [13] compared the resistance to cyclic fatigue in four rotatory endodontic NiTi instruments, three of those examined in continuous motion (K3, Profile and GT Series X) and one instrument (Safe Siders) in reciprocating motion. The tests were conducted in a laboratory with instrument size 30, with 0,04mm taper and 25mm in length. According to the tests, Safe Siders did not fractured in 5min time 1,125,000 degrees of full rotation, 30 to 45 degrees bend angles, and radius of curvature of 5 to 7mm in all the samples used in the experiment; K3 instruments Profile and GT Series showed fractures in all the samples used in the same study. However; due to variables that could not be verified without further analysis which also influence in the cyclic fatigue of NiTi instruments, this study could not determine whether the results obtained with the Safe Siders were due to its mechanical design or to its use in reciprocating motion.

Lopes, *et al.* [14] compared the flexural strength of conventional endodontic instruments and M-Wire NiTi instruments. For both, three NiTi instruments M-Wire type were used, namely: Profile Vortex (# 25, 0.06mm taper and length of 25 mm); WaveOne (# 21 0.06mm taper and length of 25mm) and Reciproc (# 25, 0.08 mm taper in the first three apical millimeters and 25mm long) and three instruments produced by conventional Revo-S SU wire (# 25 0.06mm taper and 25mm long); MTwo (# 25 0.06mm taper and 25mm long) and Race (# 25 0.06mm taper and 25mm long) .Their study showed that among all the instruments, only Race, obtained from conventional metal NiTi wire showed greater flexibility than the Profile Vortex instruments, obtained from NiTi M-wire. This contradictory behavior showed that the shape and the area of the transverse cross section of the endodontic instrument directly influence the greater or lesser flexural strength, and not only the composition of the alloy.

Gavini, *et al.* [15] assessed the resistance to flex fatigue Reiproc R25 files, 25mm, used in continuous movements and reciprocating movements. The study was conducted in laboratory assays using thirty-six R25 Reciproc files divided into two groups, according to the applied movement kinematics. The instruments operated for reciprocal movement showed almost twice the number of cycles to fracture, when compared to continuously rotating instruments .In conclusion, This study demonstrated that the use of R25 Reciproc file in reciprocating movement showed greater resistance to mechanical flex fatigue than when used in continuous rotation movement.

Arias, *et al.* [16] compared the resistance to cyclic fatigue of M-Wire WaveOne and Reciproc files on two levels. The study was conducted in laboratory, with sixty files of each brand. Half of the samples of each brand (30 files) were tested at 5 mm from their tips and the other thirty were tested 13mm from their tips, recording the fracture time. The authors concluded that Reciproc files were more resistant to cyclic fatigue than the WaveOne´s in both measures. Both systems showed improved resistance to cyclic fatigue at 5mm than in 13mm from the tip.

Ugur and Cumhur [17] compared the cyclic fatigue resistance of three NiTi instruments for endodontic retreatment. The study was conducted in the laboratory using 60 instruments: 20 R-Endo R3, 20 ProTaper D3 and 20 Mtwo R, all # 25, 05, where time and the number of cycles to fracture of each instrument was recorded. According to their study, they concluded that R-Endo R3 instruments were more resistant to cyclic fatigue than Mtwo R and ProTaper D3, due to the smaller diameter of its spirals.

Gambarini, *et al.* [18] evaluated the resistance to cyclic fatigue fracture of 30 instruments NiTi TF # 25, 0:08. The studies were performed in static block of metal canals and showed that the movement of the kinematic significantly influences the resistance to fatigue fracture of the instrument, being fracture time increased when alternate movements are used.

Castello-Escrivá, *et al.* [19] compared the cyclic fatigue resistance of three NiTi endodontic instruments: ProTaper F2, WaveOne (W.O.) and Twisted (TF). The tests were performed with a sample of 184 instruments handled in four curved artificial canals, with different angles and radii of curvature. They concluded that WaveOne instruments used in reciprocating movement showed greater resistance to cyclic fatigue than TF and ProTaper´s used in conventional rotational motion.

Lee, *et al.* [20] evaluated the cyclic fatigue of two NiTi rotary instruments with different cross sections, ProTaper F2 and Profile, used under CR (continuous rotation) and reciprocating motion (RM) with pecking motion. The studies were conducted in laboratory and concluded that there were no significant results caused by mutual action between the instrument's rotation. However, Profile showed significantly prolonged fracture resistance compared to Protaper regardless of the rotational movements used. It was also confirmed that the cross-sectional area is an important factor that influences the fatigue resistance of NiTi rotary endodontic instruments .

Higueras, *et al.* [21] compared the cyclic fatigue resistance of three NiTi instruments (K3, K3XF and TF) used in continuous and alternating rotation movements, specifically at 5mm from the instrument tip. The tests were performed in the laboratory and analyzed 210 instruments divided in seven different groups, which were tested assessing five variables able to have influence in fatigue resistance: kinematics manufacturing process, type of ally, cross-section and speed rotation. The authors concluded that fatigue was higher in all instruments when used in reciprocating motion, featuring that the heat treatment of the alloy is the only real relevant variable in this assessment.

Cheung, *et al.* [22] evaluated the effect of preloading twist on the cyclic fatigue of NiTi rotary instruments. The tests were performed in artificial canals using different profile (# 25, 00:06), and Protaper F1 instruments, each of which was evaluated in four conditions: in preload (control), 25%, 50% and 75% twist. The authors concluded that the torsional preloads within the superelastic limit of the material, can improve the fatigue resistance of NiTi rotary instruments.

Pedullà, *et al.* [23] evaluated the resistance to flex fatigue in four different NiTi rotary instruments: Reciproc 25 (R25), WaveOne Primary, Mtwo and TF. The instruments were used in two different alternating movements. The experiments were conducted in the laboratory, with a sample of 180 files, divided into three groups of 45 files each, based on motion used namely: continuous rotation, All Reciproc and WaveOne All. The authors concluded that the reciprocal movement showed higher resistance to cyclic fatigue in all brands compared to continuous rotation.

Pedullà, *et al.* [24] evaluated the cyclic fatigue resistance of Reciproc and WaveOne instruments and after immersion in sodium hypochlorite for many time periods namely: no immersion (control), 1 minute or 5 minutes. The tests were made on artificial canals of stainless steel and with endodontic engines specially designed with the recording time to fracture (TFF). The authors concluded that the cyclic fatigue resistance of the same NiTi instrument was not significantly affected by the immersion in sodium hypochlorite (NaOCl). R25 Reciproc instruments were associated with higher resistance to cyclic fatigue in all groups compared to WaveOne Primary.

Shin, *et al.* [25] evaluated the effect of the alternated motion amplitude and the progressive angular increment on the fatigue of rotary endodontic instruments. This laboratorial study was made by using ProTaper F2 instruments in stationary reciprocating (SR) and progressive reciprocating (PR) motions. The authors concluded that the lifespan of the instruments concerning fatigue increased when the amplitude in the stationary reciprocating movements decreased. In the progressive reciprocating motion with amplitude of about 45 degrees and angle of + 7, there was a significant increase in the lifespan of the instruments, but with multiple initial cracks along them.

Vadhana, *et al.* [26] evaluated and compared to cyclic fatigue resistance of the rotary instruments Race and Mtwo, in laboratory, tested in continuous rotation and alternating motion, using # 60, 25, 0.06, 25mm files, divided into four groups in accordance with the movement accomplished; the instruments were twisted to fracture and then analyzed with the aid of scanning electron microscopy. The authors concluded that the instruments of both Mtwo and Race files showed greater resistance to cyclic fatigue when rotated in comparison to the continuous movement.

De-deus, *et al.* [12] evaluated the bending strength and the cyclic, dynamic and static fatigues of the Reciproc R40 and WaveOne Large, because of the fact that the lifespan of the instrument have been extended with the use of reciprocating movements, enhancing apical preparations with thicker instruments. The instruments were custom-made devices fabricated in laboratory. The authors to concluded that Reciproc R40 instruments showed significantly higher resistance to dynamic and static cyclic fatigue than WaveOne´s. As for what concerns bending, WaveOne instruments also showed less flexibility than Reciproc.

Kiefner, *et al.* [27] compared the fatigue cyclic resistance to two geometrically similar NiTi instruments used in similar conditions for clinical application in reciprocating and continuous motions. The experiments were carried out in a laboratory using four groups of 18 instruments each: Reciproc (R25 and R40) and Mtwo (M25 and M40). The authors concluded that the reciprocation increased the cyclic fatigue resistance of the instruments and the synergistic effect achieved between M-alloy wire and the reciprocating motion was demonstrated by a significant improvement in cyclic fatigue lifespan for the instrument.

Cunha, *et al.* [28] assessed the incidence of fracture of WaveOne reciprocating file when used for preparing root canals of posterior teeth. The studies were performed in 711 human teeth, summing a total of 2,215 canals treated by four endodontists, from January 2012 to August 2013. From this total, three instruments were fractured: two WaveOne Small (# 21 ,0.06) and Primary WaveOne (# 25, 0.08). The overall incidence of fracture of the instruments in relation to the number of canals was 0.13% (0.42% teeth). Thus, the authors concluded that, according to their study, the incidence of WaveOne instrument fracture was considerably lower.

You, *et al.* [29] evaluated the modeling capability of reciprocating movement in curved canals when compared to continuous rotation motion. The experiments were performed in extracted 20 upper human molars, with bends ranging from 20º to 45º, which were instrumented with ProTaper rotary files in two proposed motions. The results were evaluated by using computed tomography. The authors concluded that the application of the reciprocating movement during instrumentation did not increase "apical transport" when compared with continuous rotation, even in the apical portion of curved canals, thus making it a viable alternative to avoid failures in the modeling process of the root canal.

Gambarini, *et al.* [18], reviewed the cyclic fatigue resistance of NiTi K3XF instruments in different reciprocal angles, observing the extent to which changes in the rotation angles could affect the lifespan of the tested instruments. For the tests, it was used 50 K3XF instruments (# 40, 0.06), divided into 5 groups, accomplished in artificial canals: Group 1 = Â 90 (clockwise = H) and 30 (anti-clockwise = AH); Group 2 = Â 150 - H and 30 AH; Group 3 = Â 210 - H-30 and AH; Group 4 = Â 390º - H and 30 AH, and group 5 = control (continuous rotation). The authors concluded that the null hypothesis was rejected, because the results clearly showed that the kinematics motion plays a significant role in the lifespan of cyclic fatigue of the NiTi instruments tested. Furthermore, the speed can also play an important role in the process, since it has been shown that, by increasing the rotational speed, it is possible reduce the lifespan of the instrument. This hypothesis therefore points to further research on how to define and measure the speed in a reciprocating motion, as well as to determine which alternative motions are the most convenient for endodontic use.

Bulem, *et al.* [30], evaluated the cyclic fatigue resistance of four different NiTi instruments after immersion in sodium hypochlorite and/or sterilization in autoclave. The following instruments were used in the study: Profile, Flexmaster, Mtwo and Twisted (# 25, 0.06). A total of 160 instruments were divided into four groups namely: dynamically immersed in NaOCl; immersed in NaOCl and sterilized in one autoclave cycle, immersed in 5 cycles of NaOCl and sterilized by autoclaving without immersion in NaOCl; and without sterilization (control group). The cyclic fatigue resistance was tested and the number of cycles to failure (NFC) was analyzed satisfactorily. According to the tests, there were significant differences between instruments in NFC terms, showing a higher rate of cycles to fracture for Mtwo (556.75). The immersion in NaOCl and autoclaving showed no effects on the number of cycles to fail values. The authors concluded that the cyclic fatigue resistance of NiTi instruments could not be adversely affected by the immersion in NaOCl and autoclaving, and added that the manufacturing process (Twisted) or design (Twisted, Flexmaster, Mtwo and Profile) of the instruments may influence their resistance to cyclic fatigue.

Pedullà, *et al.* [31], reviewed the cyclic fatigue resistance of NiTi instruments M-wire (Reciproc and WaveOne) and conventional NiTi (Protaper F2) after immersion in NaOCl irrigating solutions and in ethylenediamine tetra-acetic acid (EDTA) with or without surfactants (substances added to irrigating solutions to reduce surface tension, increasing the penetration capacity in the dentinal tubules). The tests were performed at short periods, similar to those used in the clinical practice. The authors concluded that immersion in NaOCl did not reduce cyclic fatigue resistance of reciprocating or continuous rotation NiTi instruments. The 17% EDTA reduced the fatigue strength of all the instruments after 3 minutes. Concerning the surfactants, reduction of fatigue resistance to Reciproc only occurred when they were immersed in surfactant with NaOCl (hypochlorite solution), which may be due to the cross section of the instrument.

Casper, *et al.* [32] compared the effects of multiple cycles of autoclaving in fracture resistance and torsional deformation of three instruments: Profile Vortex (PV), Twisted Files (TF) and files produced with CM Wire alloys (CM). The tests were performed by dividing instruments in five groups: 1, 2, 3, 7 sterilization cycles and a control group without sterelization. The authors concluded that autoclaving cycles had no significant effect on the overall performance of the tested instruments.

Gambarini, *et al.* [33] investigated if the cyclic fatigue resistance of NiTi instruments manufactured with different thermal treatments would be increased in the rotational clockwise or counterclockwise motions. The tests were performed in artificial devices simulating curved canals. It was used instruments with stage R heat treatment (Sybron Endo-K3XF) or instruments with M-Wire alloy (Profile -Vortex). Their results showed no significant difference in resistance to cyclic fatigue when NiTi instruments were used in any of the two directions of movement.

Pessoa, *et al.* [34] evaluated the cyclic fatigue resistance of NiTi rotary instruments after simulated clinical use in curved canals. Thirty-six instruments were used: Race (# 5, 0.04), divided into three groups, with three and five cycles of use, respectively, correlating time to fracture. Their results showed that the number of clinical uses of instrument affected negatively the fatigue resistance after five cycles of use.

Pirani, *et al.* [35] evaluated the cyclic fatigue resistance of ProTaper F2 and WaveOne Primary instruments after analysis of surfaces fractured under light microscopy. The studies were performed in the laboratory, by using artificial curved canals, with curvature radius of 5mm and 60° curvature angle. Seventy two instruments were divided into three groups (n = 24) according to the kinematics of movement used. The results showed significant differences in group A (WaveOne), which was more resistant to fatigue. Surface analysis showed the presence of deep grinding marks on both instruments, as well as revealing multiple sources of slots for WaveOne, and unique origin to ProTaper, suggesting therefore extended working time in clinical applications for WaveOne.

3. Discussion

Fracture resistance seems to be quantified by the number of cycles that an instrument is able to resist after a given load condition. The search for continuous improvement in Endodontics has been consolidated with the increasing use of automated instrumentation, which not only enhances the quality of the instrumentation and the shaping of the root canals, as it also saves time, making the treatment less complicated. However, despite the proven effectiveness in relation to the working time and the modeling (especially in curved canals), decreased apical transportation and consequently higher success rates in the prognosis of the treatments, NiTi instruments may suffer premature failure by bending, torsion or cyclic fatigue, which is influenced by several factors, some of them highlighted in this review. Some variables may influence the cyclic fatigue resistance of NiTi instruments: kinematic motion used, alloy composition, different rotational angles and the speed used, as well as the shape and area of the cross section of the straight instrument. However; as for the methodology used by the majority of the articles, it is usually based on experimental artificial canals, which do not faithfully reproduce the arc length and radius of the curved channel, or extracted teeth.

With regards to the influence of the alloys of the instruments, [14] demonstrated that this fact itself is not decisive in greater or lesser flexural strength, which corroborates the statements of AL-Hadlaq, *et al.* [10] and Higueras, *et al.* [21], who consider the heat treatment of the alloy is a relevant variable, making M-Wire alloys the most flexible and consequently more resistant to cyclic fatigue.

As for what concerns the kinematics of movement, [15] demonstrated that Reciproc R25 file in reciprocating motion showed higher mechanical resistance to flex fatigue than when used in continuous rotation; this finding is emphasized by Wan, *et al.* [13] who found that the three instruments used in continuous movement did fracture, according to the conditions of test employed, while the instrument used in reciprocating movement did not. Other authors such as [21]; [18]; [36]; [19]; [23]; [27] were unanimous in concluding that instruments operated in reciprocating movement fracture less than those used in continuous rotation preventing, as considered by [29], the "transport the foramen", even in the apical third of curved canals.

Another factor evaluated was the influence of the instrument immersion in sodium hypochlorite as for what concerns their fatigue strength. Pedullà, *et al.* [23] concluded that there was no considerable improvement. Further evaluation with scientific criteria concerning the immersion in sodium hypochlorite and EDTA, with or without surfactants, conducted by these same authors, in 2014, found that immersion in NaOCl did not reduce resistance to cyclic fatigue in reciprocating or continuous rotation NiTi instruments. Nevertheless, the 17% EDTA reduced the fatigue strength of all the instruments after a 3 minute period. In relation to the surfactants, reduction fatigue strength only occurred to Reciproc when immersed in surfactant with NaOCl (Hypoclean solution), which may be due to the cross-sectional shape of the instrument.

By analyzing the influence of autoclaving cycles in fatigue resistance, [32] concluded that these had no significant effect on the overall performance of the tested instruments. Additionally, other authors (Ureyen BULEM Kaya, Ayse Diljin KECECI, Hilmin Egemen GULDAS) concluded that the instruments were not adversely affected either by immersion in sodium hypochlorite, or by autoclaving.

Regarding the influence of different reciprocal angles used in reciprocating movements, [33] evaluated the extent to which changes in these angles might affect the lifespan of the instruments and claimed that by increasing progression angle for each reciprocating movement cycle, the resistance to cyclic fatigue is reduced. When tested and assessed, all of the groups of instruments used in alternate movements showed a significant increase in fracture time as compared to the instruments in continuous rotation (control groups). In addition, the rotation speed used in motion may also play an important role in the process, since if it is increased there may cause a decrease in the lifespan of the instruments. This hypothesis therefore points to further research on how to define and measure the adequate speed used in a reciprocating motion, as well as to determine which alternative movements are the most convenient for endodontic practice.

Shafer and Tepel [7], the shape and area of the cross straight section are the main parameters influencing the behavior in the bending of the endodontic instruments. For Shafer and Florek [6] there is a strong correlation between the area of the cross section line and the rigidity of the instruments. So it can be assumed that the larger the diameter of the area and the shape of the straight cross section, or taper, of the endodontic instruments the largest is the rigidity thereof. This indication is also confirmed by [20] when they came to the conclusion that Profile showed significantly higher fracture resistance when compared with Protaper F2, regardless of the rotational motion used, and attributed therefore such improved resistance to fact that the instruments had different cross sections. The different studies on the analysis of the cyclic fatigue resistance of nickel titanium endodontic instruments point to several factors that can work together or separately to determine the effectiveness of the instrument as to their lifespan. Probably, the numerous existing variables such as the methods used and the diversity of the instrumental brands contribute to the conflicting results in the available in the literature.

Although the use of extracted teeth may have an intimate correspondence to actual clinical situations, they are not ideal for the analysis of fracture cycles simply because they are not standardized, thus generating conflicting results. The best way to play cyclic fatigue is to repeat the movement for all instruments in the same pre-defined curvature, avoiding the sites where the additional sites of torsional stress of the instrument will appear

Based on the above, a further deepening of the research in relation to the mechanical behavior of endodontic instruments of nickel-titanium, especially those classified as mechanized during laboratory tests and during clinical use is essential, so that better parameters are presented as determinants of greater or lesser resistance to cyclic fatigue of these technological instruments.

4. Conclusion

Kinematic motion, alloy composition, different rotational angles and the speed used, as well as the shape and area of the cross section of the straight instrument seem to play an essential role for fracture resistance of NiTi rotary endodontic instruments.

Further studies, especially those using extracted human teeth in their models, are necessary to establish more consistent and determinants results than what leads to more or less cyclic fatigue resistance of nickel-titanium endodontic instruments.

5. Conflict of Interest Disclosure

The authors declares that there is no conflict of interest regarding the publication of this paper.

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