Differences in Cyclic Fatigue Resistance between ProTaper Next and ProTaper Universal Instruments at Different Levels

Juan J. Pérez-Higueras, DDS, Ana Arias, DDS, PhD,[†] José C. de la Macorra, DDS, MS, PhD,* and Ove A. Peters, DMD, MS, PhD[†]*

Abstract

Introduction: New designs and alloys have been developed to increase cyclic fatigue (CF) resistance of rotary files. The aim of this study was to compare CF resistance of ProTaper Universal (PTU; Dentsply Tulsa Dental, Tulsa, OK) and ProTaper Next (PTN, Dentsply Tulsa Dental) instruments at different points of curvature. **Methods:** A total of 420 files (240 PTU, S1, F1, F2, and F3 and 180 PTN, X1, X2, and X3) were divided in 14 groups of 30 instruments each. Instruments in groups S1–5, F1–5, X1–5, F2–5, X2–5, F3–5, and X3–5 were tested at 5 mm from the tip. Groups S1–12, X1–12, and F1–12 were tested at 12 mm from the tip because S1, X1, and F1 instruments have the same diameter at that level. Groups F2–8, X2–8, F3–8, and X3–8 were tested at 8 mm (F2/X2 and F3/X3, respectively, had the same diameter at 8 mm). All files were rotated at 300 rpm until fracture. CF resistance was tested in stainless steel curved canals (60°, $r = 3$ mm). Time to fracture was recorded. The mean half-life and beta and eta were calculated for each group and were compared with Weibull analysis. **Results:** PTN instruments will last significantly longer than PTU files with a probability higher than 98% at all tested levels except for S1, which was the significantly the most resistant instrument to CF at 5 mm from the tip. **Conclusions:** PTU S1 was significantly the most resistant instrument at 5 mm from the tip. PTN files were significantly more resistant to CF than PTU instruments at all the other tested levels. *(J Endod 2014;40:1477–1481)*

Key Words

Cyclic fatigue resistance, M-Wire, ProTaper Next, ProTaper Universal, Weibull analysis

From the *Department of Conservative Dentistry, School of Dentistry, Complutense University, Madrid, Spain; and [†]Department of Endodontics, Arthur A. Dugoni School of Dentistry, University of the Pacific, San Francisco, California.

Address requests for reprints to Dr Ana Arias, Arthur A. Dugoni School of Dentistry, University of the Pacific, 2155 Webster Street, San Francisco, CA 94115. E-mail address: aa@ana-arias.com

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Nickel-titanium (NiTi) rotary files have become popular instruments to shape root canals (1) because of their elasticity, efficiency (2, 3), and cutting capacity (4). However, these instruments undergo repetitive strain excursions (5) rotating in curved canals and hence tend to unexpectedly break because of cyclic fatigue (CF) (6–8).

Many factors (eg, the radius and degree of the root canal curvature and the design of the instrument) are believed to have an influence on the CF resistance of files. However, manufacturers recently enhanced the fracture resistance of NiTi files by the improvement of manufacturing processes and the development of new alloys with superior mechanical properties when compared with conventional NiTi (5, 9, 10).

A novel thermomechanical process optimizes the microstructure of NiTi producing the so-called M-Wire alloy (Sportswire LLC, Langley, OK). Endodontic instruments manufactured with this alloy are expected to have an increased flexibility and higher strength and wear resistance than similar instruments made of conventional superelastic NiTi wires because of its unique nanocrystalline martensitic microstructure (11). In recent years, superior mechanical properties of files manufactured with M-Wire (12–14) have been shown.

Manufacturers have also introduced different designs to improve CF resistance of files. ProTaper Universal (PTU; Dentsply Tulsa Dental, Tulsa, OK) is a well-described NiTi rotary system of instruments manufactured with progressive taper over the length of the cutting blades, convex triangular cross-sections, and noncutting tips. Recently, ProTaper Next (PTN, Dentsply Tulsa Dental) has been developed with the new M-Wire alloy; its design features include variable tapers and an off-centered rectangular cross-section.

As per directions for use, clinicians should take all instruments in both series, except ProTaper SX, passively to the working length after preparing a glide path (15, 16). However, although the basic sequence to shape curved root canals with PTU includes 6 instruments, 3 of them to prepare the coronal and middle third (SX, S1, and S2) and the other 3 to enlarge the apical third (F1, F2, and F3), PTN directions for use suggest the use of only 3 files to shape similarly sized canals (X1 is #17/.04, X2 is #25/.06, and X3 is #30/.075). The tip diameter of X1 is close to S1, but the increment in the taper throughout the active blades is closer to the F1 PTU instrument. The action of X1 could be the substitution of S1, S2, and F1 PTU files. M-Wire raw material has also shown an extended fatigue life beyond the conventional NiTi alloy (17, 18), which may allow getting the final desired shape with fewer instruments without increasing the risk of failure because of CF.

Currently, there are no reported data available on CF resistance of PTN files, and no studies have compared CF resistance of this new system of instruments and the predecessor PTU. Therefore, the aim of this study was to compare CF resistance of PTN and PTU files at different levels.

Materials and Methods

A total of 420 files (240 PTU and 180 PTN) were divided into 14 groups ($n = 30$ in each). In 7 groups (S1–5, F1–5, F2–5, F3–5, X1–5, X2–5, and X3–5), CF resistance was tested at a distance of 5 mm from the tip. In the other groups (S1–12, F1–12, F2–8, F3–8, X1–12, X2–8, and X3–8), CF resistance was tested at the level where the specific PTN and PTU instruments had the same diameter. The matching diameters of comparable instruments were at 12 mm from the tip for S1, X1, and F1; at 8 mm for F2 and

X2; and at 8 mm for X3 and F3. Therefore, the other tested level was at 12 mm from the tip for groups S1–12, X1–12, and F1–12 and at 8 mm for groups F2–8, X2–8, F3–8, and X3–8. The diameter of all instruments at 5 mm from the tip and at the other tested level is shown in Figure 1.

The experiment was performed in a device that was previously described in detail (19–21). In brief, this device consists of a hardened stainless steel form block with 11 carved open semicanals (2 straight opened portions are joined by a 60° curvature with a 3-mm radius) with diameters ranging from 0.4 to 1.4 mm and a depth 0.1 mm greater than each width. The hardened form block was attached to a base that allowed manual adjustment of its position in the 3 axes of space. The x-axis held the dental handpiece and could be approached or separated from a second platform that held the stainless steel carved piece. This second platform adjusted the vertical (y-axis) and depth (z-axis) positions of the canals. The final position of the files was controlled by visual inspection under an operative microscope. A swiveling top face cover allowed the visualization of the files and protected the operator. The immediately wider canal (to the nearest 0.1 mm) to the diameter of the instrument at the entrance of the canal, 5 mm short of the fatiguing point, was selected to test CF.

All instruments were rotated until fracture at the speed specified by the manufacturer (300 rpm). After positioning the instrument in the canal and lubricating with synthetic oil (Singer All-Purpose Oil; Singer Sewing Company, Barcelona, Spain) to minimize friction, the motor and a 1/100s chronometer were simultaneously activated. The instrument was monitored through the face cover during the test until fracture and time (seconds) to fracture were registered.

Weibull analysis (Weibull ++ 7; Reliasoft Corporation, Tucson, AZ) was used to calculate the following parameters and their 95% confidence intervals for each group:

1. Mean life (seconds), the expected or average time to failure.
2. Beta (β) (dimensionless), the slope or shape parameter: the values of which are equal to the slopes of the regressed lines in the Weibull probability plot and are particularly significant because they provide a clue to the physics of the failure.
3. Eta (η) (seconds), Weibull characteristic life or scale parameter: the typical time to failure in Weibull analysis related to the mean time to failure. It is defined as the time at which 63.2% of the files are expected to fail (ie, the probability of failure being 0.63 at this time point).

Comparison between groups allowed for the determination of whether items from 1 set would outlast those of the others.

Results

Weibull probability plots (unreliability, or the probability of failure, vs time) per group for comparable files are shown in Figure 2 (S1–5, F1–5, F2–5, F3–5, X1–5, X2–5, and X3–5 groups; S1–12, F1–12, and X1–2 groups; F2–8 and X2–8 groups; and F3–8 and X3–8 groups). Mean life and eta and beta parameters and their 95% confidence interval are shown in Figure 1.

PTN instruments will last significantly longer than PTU with a probability higher than 98% either at 5 mm from the tip or at the other tested levels except for S1, which was the significantly most resistant instrument to CF but only at 5 mm from the tip.

Although S1 had a 11.3% longer lifespan than X1 and 83% more than F1 on average at 5 mm from the tip, when compared at a level with the same diameter (12 mm from the tip), X1 resisted 46% more time than F1 and 50% more time than S1. In fact, S1–5 showed the highest η value (69), whereas S1–12 showed the lowest (1.26).

For PTU instruments, S1 was the most resistant, F1 was significantly more resistant to cyclic fatigue than F2, and F2 was more resistant than F3. For PTN files, X1 was significantly more resistant to cyclic fatigue than X2, and X2 was more resistant than X3.

Beta values were higher than 4.3 in all groups, indicating a predictable behavior of all the instruments at both levels. This fact is also shown in the steep slope of all groups in Figure 2.

Discussion

CF resistance of files has been improved with the development of new alloys, but it is still a concern for endodontists, general practitioners, and patients. Two topics could be improved in research related to CF resistance of endodontic instruments. On the one hand, the absence of standardized specifications to test CF of rotary NiTi instruments makes well-designed studies necessary that try to minimize uncontrolled variables and to reproduce the same conditions (22, 23). On the other hand, a consensus between researchers should be reached in the correct statistical analysis of data derived from the mean life of instruments (24, 25).

To date, various methods have been developed to test CF resistance of files in metal devices simulating canals (26–28). However, others tried not to reproduce a complete canal but rather to have a reproducible situation (eg, the classic 3 stainless steel pins that constrained the instrument into a curvature) (29–31). An effort to minimize uncontrolled variables and to reproduce the same conditions to test CF resistance of instruments is desired. The device used in this study tried not to reproduce a clinical condition but rather to test files in a controlled and repeatable environment that excluded all possible confounding factors and in which results approached the intrinsic properties of tested instruments.

The benefit of this device is that the operator can decide the fulcrum point for the fatigue test because it included different sizes of open-ended hardened steel semicanals. Two different levels for all instruments were selected to test CF resistance: at 5 mm from the tip and at another level, the location of which depended on the taper and diameter of each instrument along their active blades. In each case, a level was chosen that was associated with the same cross-sectional diameter to facilitate comparisons; this way the test assessed the relevance of a particular design and alloy of the instruments and avoided confounding factors like the mass of metal.

Fatigue is a process in which damage accumulates because of the repetitive application of loads below the yield point (32). Quantitative accelerated life tests are designed to produce the data required for accelerated life data analysis, gathering life data obtained under accelerated conditions to foretell the behavior for the product under normal use conditions (33).

A conventional statistical approach is often used to analyze CF resistance of files although such methodology does not consider crack generation, buildup, or alteration of pre-existing defects of materials as accumulative. Measured along time, a single application of the load could possibly not produce any defect, so a conventional stress analysis might lead to the assumption of a safety that does not exist (34). Determining a Weibull distribution leads to a more accurate approximation (25, 35, 36). Weibull risk-of-rupture analysis is a widely accepted model for material and structural evaluation and is the leading method in the world for fitting and analyzing life data (37). The Weibull distribution is used to predict the failure times of products. A simple plot is drawn to visualize the observations in which the unreliability of the specimens is found on the ordinate and the observation time on the abscissa.

System	Instrument	Group	Tested level (mm from tip)	Diameter at tested level (mm)	**Mean life** (CI 95%)	**β** (CI 95%)	**η** (CI 95%)
PTU	S1	S1-5	5	0.37	63,6 (53,8 – 68,7)	5,4 (4 – 7,3)	69 (64,3 - 74)
		S1-12	12	0.98	1,2 (1,1 – 1,3)	7,8 (6,3 – 9,7)	1,26 (1,19 - 1,34)
	F1	F1-5	5	0.54	10,8 (9,8 – 11,8)	5,7 (4,1 - 8)	11,6 (10,7 - 12,6)
		F1-12	12	0.92	1,3 (1,2 – 1,4)	7 (5,5 - 9)	1,4 (1,3 - 1,5)
	F2	F2-5	5	0.62	7,4 (6,7 – 8)	6 (4,3 - 8,4)	7,9 (7,3 - 8,6)
		F2-8	8	0.78	4,3 (3,8 – 4,8)	4,4 (3,1 - 6,3)	4,7 (4,2 - 5,2)
	F3	F3-5	5	0.69	2,0 (1,9 – 2,2)	11,2 (8,6 - 14,7)	2,1 (2,0 - 2,2)
		F3-8	8	0.83	1,9 (1,7 – 2,1)	8,2 (6,3 - 10,6)	2 (1,9 -2,2)
PTN	X1	X1-5	5	0.42	56,4 (51,3 - 62,1)	5,5 (3,9 - 7,7)	61,1 (56,2 - 66,5)
		X1-12	12	0.92	2,4 (1,6 - 3,5)	7,7 (3,3 - 17,8)	2,5 (1,8 - 3,6)
	X2	X2-5	5	0.56	29,1 (25,6 - 33)	4,3 (3,1 - 6)	32 (28,7 - 35,7)
		X2-8	8	0.77	9,8 (8,4 - 11,4)	4,6 (3,4 - 6,1)	10,7 (9,4 - 12,2)
	X3	X3-5	5	0.65	5,3 (4,6 - 6,1)	6,4 (4,8 - 8,7)	5,7 (5,1 -6,4)
		X3-8	8	0.83	4,5 (4,1 - 4,9)	6,8 (5 - 9,2)	4,8 (4,5 - 5,2)

Figure 1. The diameter of instruments at tested levels and mean life (seconds) and beta (dimensionless) and eta (s) parameters (and 95% confidence interval). Note that PTN instruments had higher CF resistance than PTU at all tested lengths except for S1 instrument at 5 mm from the tip.

The double logarithmic scale of the ordinate of such a plot makes the Weibull cumulative distribution function appear as a straight line in which the β parameter is the slope of the line (38). The steeper the slope (β) of the plot, the smaller the variation in the time to failure and the more predictable the results will be (37).

In this report, CF resistance of PTN and PTU was tested at different levels. As expected, a higher mean life was found at apical than at coronal levels for all instruments. A possible explanation for this result might be the larger cross-sectional diameters that produced higher local strain rates (39). At the same time, defects such as pits, metal strips, longitudinal scratches, and milling grooves have been shown to be larger near the handle of the instrument than near the tip (40). A β value lower than 1 would have shown that failure rate is decreasing with time. Failures that occur at a relatively early time are caused by massive flaws; however, β values were higher than 4.3 for all groups in the present study, showing a predictable behavior of files at both levels, which is also shown in the steep slopes of all curves in Figure 2.

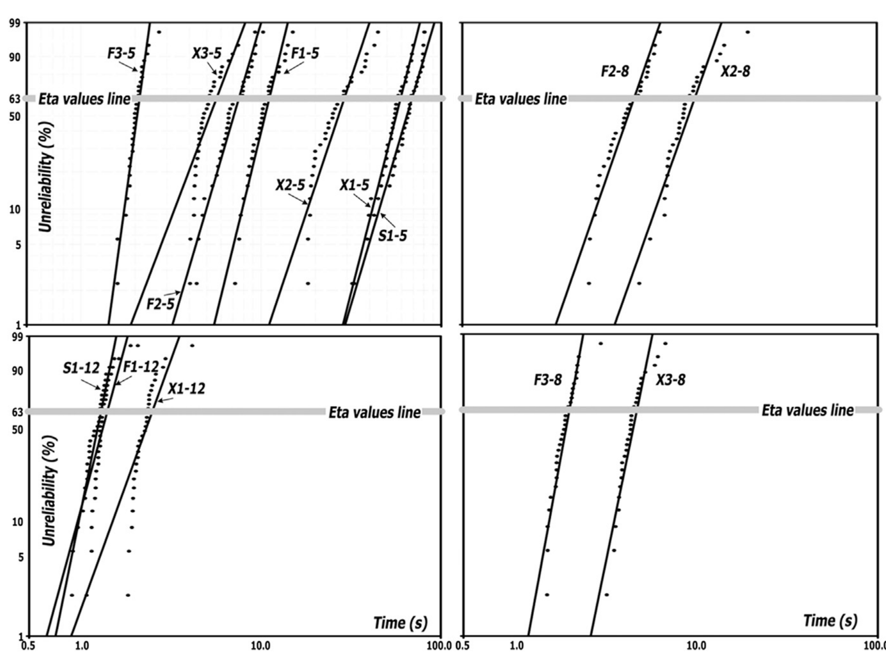

Figure 2. Weibull probability plots: unreliability versus time (both axes in logarithmic scale). The eta values line intersects with the time at which 63.2% of the instruments are expected to fail.

In addition, there is a negligible probability of failure during the use of an instrument when Weibull characteristic life or η is beyond the time that the instrument is expected to be active. The time that an instrument is working at a specific level when shaping a root canal normally in the clinic is lower than the η obtained in all groups even though the test curvature used in this study was strong.

In accordance with other studies, the results for both PTU and PTN showed a decrease in the resistance to CF with an increase in the instrument diameter (41). The results of the present study showed that PTN instruments had higher CF resistance than PTU at all tested lengths, apart from the S1 instrument, which has the smallest diameter (0.37 mm) at 5 mm from the tip. Two different characteristics of each rotary system could be responsible for the differences in CF resistance; both are made of a different NiTi alloy and have different cross-sections. PTU instruments are made of the conventional NiTi alloy and have a triangular cross-section, and PTN is made of M-Wire and has an off-centered rectangular cross-section.

It has been shown that cross-sectional design has an impact on the stress developed by an instrument under either tension or bending (42, 43); PTU instruments showed lower resistance to CF than other instruments in previous studies, and it was attributed to the stiffness of the instruments (44). However, recent studies claimed the superiority of M-wire (19, 45–47).

It has been also been reported that static CF tests showed lower results compared with dynamic tests in which endodontic instruments are subjected to axial movements (48). The alternating compressive and tensile stresses are likely concentrated at the same area of the instrument in static tests, creating cumulative stresses and inducing microstructural changes in the metallic alloy (49). Therefore, higher CF resistance is expected in a clinical situation in which instruments are operated in a constant in and out motion that helps to avoid taper lock.

Within the limitations of this *in vitro* study, the results suggest that a higher resistance to CF is expected for the different instruments in PTN sequence when compared with PTU instruments except for S1 PTU at apical levels where the instrument is thinner than X1 PTN.

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The authors deny any conflicts of interest related to this study.

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