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Enhanced cyclic fatigue resistance in endodontic rotary instruments: challenges and innovations

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Background: Root canal cleaning and shaping are crucial in endodontic treatment, but curved root canals present challenges. Nickel-titanium (NiTi) rotary devices have transformed this surgery due to their shape memory and super-elastic nature. However, cyclic fatigue remains a major issue, causing microfractures in the metal matrix. NiTi alloys' fatigue resistance has been improved through design, manufacturing processes, and thermomechanical processing. CM-Wire's NiTi alloys show potential due to heat-treated NiTi. Cyclic fatigue resistance is influenced by file form, rotation speed, and canal curvature. The irrigation usage of sodium hypochlorite (NaOCl) during instrumentation can also impact file performance. **Aim:** This work intends to investigate, by means of design modifications, manufacturing procedures, and environmental variables, the cyclic fatigue resistance of existing NiTi rotary instruments under different conditions. This study aims to maximize endodontic techniques and enhance patient outcomes by means of comparison of results of current studies. It will stress the benefits and drawbacks of numerous file systems. generally speaking. **Conclusion:** Particularly in devices using novel thermomechanical processing and heat treatment, recent improvements have greatly enhanced the cyclic fatigue resistance of NiTi rotary instruments. Protaper Gold, Reciproc Blue, and HyFlex EDM are among the file systems shown to be most successful. The intricacy of optimal file performance is highlighted by the effects of canal curvature, operational factors, and environmental conditions—such as temperature changes and NaOCl exposure. These modifications have not addressed cycle weariness, a problem particularly problematic in too curved canals. Future research should keep searching for creative manufacturing technologies and design ideas that increase the durability and efficiency of NiTi rotary instruments thereby enhancing clinical results and reducing the risk of instrument separation.

Keywords: Root canal instrumentation, Nickel-titanium (NiTi) rotary instruments, Cyclic fatigue resistance, Heat-treated NiTi alloys, Thermomechanical processing.

Introduction

Endodontic treatment relies heavily on cleaning and shaping root canals; nevertheless, curved root canals sometimes cause problems such as ledge formation and non-tapered hourglass forms. To overcome these challenges, nickel-titanium (NiTi) rotary shaping procedures were developed. Files are susceptible to microfractures caused by cyclic fatigue, a continual cycle of compressive and tensile forces. These microfractures can eventually lead to file fractures. Rotating NiTi files are typically discarded by clinicians after a specific amount of usage, primarily due to cyclic fatigue. The fatigue resistance of NiTi alloys has been enhanced through advancements in file design, manufacturing procedures, and preparation techniques. Using patented thermomechanical processing, both CM-Wire and standard NiTi have been improved to provide superior resistance to cycle fatigue. Fatigue resistance is assessed using various factors, with NaOCl being deemed the optimal irrigating solution for disinfection.[1]

For microstructure and cyclic fatigue, Pirani et al. (2016) examined HyFlex EDM and CM files. In canals with significant curvature, fifteen HyFlex EDM files and twenty HyFlex CM were subjected to cyclical fatigue testing. In order to compare the microstructure of both new and old HyFlex EDM equipment, an ESEM examination was conducted using an energy dispersive X-ray spectrophotometry (EDS) device. The HyFlex EDM files performed admirably in the cyclic fatigue test. According to structural research, HyFlex EDM's defining characteristic is its spark-machined distinctive surface. Despite extensive testing, the HyFlex EDM file showed only minor surface degradation.[2]

When it came to torsional and cyclic fatigue, Pedullà's 2016 study compared HyFlex EDM, Reciproc R25, and WaveOne. Each of the 120 new files used for testing was carefully reviewed before being executed. We tested the torsional fatigue resistance of various file brands by fixing each one 3 mm from the tip, spinning it until a crack appeared, and then measuring the torque and speed. Twenty new files were tested for cycle fatigue using a specialized device in a metal canal that had a 3mm radius and a 60´angle of curvature. Additionally, the test captured the precise second at which every file corrupted. Hyflex EDM had better cycle fatigue resistance and rotation angle, whereas WaveOne and Reciproc R25 had better torque to failure.[3]

In order to evaluate the wear resistance and cyclic fatigue of HyFlex EDM, Iacono et al. (2016) used a synthetic metal canal with a 70´º angle of curvature to spin twenty instruments from each manufacturer. Before and after surgery, we evaluated the surface characterisation of twenty-one EDM files that were used to instrument the curved roots of extracted teeth. We employed a scanning electron microscope to determine the files' wear resistance. The file's surface looked brand new even after multiple uses, thanks to the wear-resistant EDM. Additional results demonstrated substantial cycle fatigue. Subjecting the file to electric discharge improves its mechanical characteristics.[4]

A synthetic metal block with the following dimensions: 1.5 mm diameter, 60´ angle of curvature, and 3 mm radius of curvature was used to test the cycle fatigue resistance of ten instruments from each group. This approach was incorporated in the evaluation of torsional and cyclic fatigue by Kaval et al. (2016). Kaval et al. measured the torsional strength by recording the maximum torque and angle of deflection when the object was spun clockwise at a rate of 2 revolutions per minute. Despite sharing an identical cross-section, Protaper Gold outperformed the other tape in terms

of torsional strength and resistance to cycle fatigue. Among the many types of cycle fatigue resistance, HyFlex EDM was the most effective.[5] Özyürek and Gündoğar (2017) assessed the cycle fatigue of WaveOne Gold, Hyflex EDM, Reciproc Blue, and OneShape. Thirty files from each manufacturer were rotated using molded stainless-steel canals that had inner diameters of 1.5 mm, radii of curvature of 5 mm, and an angle of 60º. We left the files to spin for the required amount of time once a fracture occurred. Hyflex EDM showed the most resistance to fatigue from cycles, whilst One Shape showed the lowest. Reciproc Blue has a higher resilience to cycle fatigue than Wave One. None of the categories showed a statistically significant difference in the length of the broken piece.[6]

The cycle fatigue for straight and curved canals was compared by Yilmaz et al. (2017) using forty path files from Proglider, Hyflex EDM, and OneG. The twenty files were examined in a metal canal that was bent twice: once at an angle of 60´ and 8mm from the tip, and again at an angle of 70´ and 2mm from the tip. Fifty additional files from each brand were tested using a single bent metal channel that was 60´ and 5mm from the file tip. The length of the shattered piece and the time it took for the break to occur were determined by Yilmaz et al. (2017). Furthermore, the type of fracture was determined by examining twelve files using a scanning electron microscope. Cycle fatigue was greater in the single-curved canal for the EDM route files, even though resistance was lower in the double-curved canal.[7]

Reciproc, WaveOne, and TF Adaptive's cycle fatigue resistance was measured by Özyürek et al. (2016). Twenty files from each brand were subjected to a dynamic model. Every tool was subjected to rotation until it snapped in a stainless-steel model of a 1.5 mm ID, 5 mm radius, and 60 º angle of curvature canal. A precise mechanism was employed to achieve the 3 mm/s amplitude dynamic movement. Results were slightly better for Reciproc, however TF Adaptive had far less cycle fatigue compared to the other two files.[8]

In a study conducted by Grande et al. (2017), the fatigue life of various heat-treated nickel-titanium alloys was examined at low ambient temperature circumstances. A total of forty fresh samples were utilized for each of the following: ProTaper Universal F2, ProTaper Gold F2, Twisted Files SM2, Mtwo #25.06, and Vortex Blue #30.04 and #40.06. Twenty instruments were tested at 20˚C (±2˚C) in the room temperature group, and twenty instruments in the cooled environment were tested at -20˚C (±2˚C) in the same environment. The length of the broken piece and the number of cycles till failure were both noted. Across all evaluated systems, the mean NCF values were significantly greater in the CE groups compared to the RT groups ($P < .05$). A 274% to 854% improvement in fatigue resistance was seen. ($P < .05$) There were no discernible variations in FL across the various categories.[9]

Alfawaz et al. (2018) split 135 ProTaper Gold F2 instruments evenly across 9 groups. The cycle fatigue resistance of the instruments was subsequently tested by immersing them in a sodium hypochlorite solution of varying temperatures and concentrations. With the use of a block that has man-made canals that are 60 degrees curved and five millimeters in radius. A simple mixture of distilled water and 2.5% sodium hypochlorite (NaOCl) will teach you how to set a block. Temperatures of 25, 37, or 60 degrees Celsius were pre-programmed for Alfawaz et al. At 25°C, the PTG F2 fracture threshold was highest in distilled water, while at 60°C, it was lowest in 5.25% NaOCl. Fatigue resistance was decreased when the surrounding temperature was raised and sodium hydroxide was used as the irrigation solution

instead of distilled water. At various temperatures and concentrations, Alfawaz et al. found that the irrigating solution's NaOCl affected the cyclic fatigue resistance of PTG instruments.[10]

Two different kinds of files were tested for cyclic fatigue properties by AlShwaimi et al. Here are the files that were used: ProTaper Universal (PU), ProFile Vortex (PV) from M-wire, and Proflexendo (PE) from CMT. There was little difference between the three sets of files in terms of cross-sectional shape and tip size. The specific goal of developing a cyclic fatigue device was to determine the number of cycles needed for each system to fail. He concluded that the production method significantly affected resistance to cycle fatigue. Despite sharing comparable taper and tip diameters, the controlled memory Ni-Ti Proflexendo files had a longer cycle to failure than the M-wire ProFile Vortex files.[11]

Among the innovative instruments whose cyclic fatigue resistance was measured by Elnaghy et al. (2018) were One Curve (OC), 2Shape (TS), Vortex Blue (VB), ProFile Vortex (PV), and RaCe (RC). The files were tested using the simulated canals to make sure they were all 25/.06 in size. The radius for single curves was 5 mm and the curvature for double curves was 2 mm, with a range of 60 degrees in between. In a saline solution maintained at 37°C ± 1°C, the samples were deposited. We determined the NCF, which stands for number of cycles till failure. Compared to its rivals, the VB instrument had significantly better fatigue resistance. The cycle fatigue resistance of OC and TS instruments is higher than that of PV and RC instruments.[12]

Dynamic cycle fatigue was mainly affected by the angle of file access, OC files had more cyclic fatigue resistance than EZ files, and coronal curvatures had a detrimental effect on cyclic fatigue resistance rather than apical curvatures.[13]

Scout RaCe path files, HyFlex GPF, and HyFlex EDM were all measured for their mechanical qualities in a 2018 study by NISHIJO et al. The EDM HyFlex pathfiles outperformed the Race scout files in terms of fracture resistance in a prototype test of an automated root canal preparation system. This three-pin device has a radius of 5 mm and a curve of 60°; it may be rotated clockwise or counterclockwise at 300 rpm. When the pathfiles were rotated counterclockwise, they exhibited enhanced resistance to fatigue from cycles. By positioning the file three millimeters from the tip using a designated device, HyFlex EDM demonstrated higher torsional strength in the testing. When compared to GPF, EDM and RaCe had lower bending loads and angular deflection values.[14]

From 2018 to 2015, Özyürek et al. investigated the cycle fatigue resistance in artificial St. using Wave One gold, Reciproc Blue, Hyflex EDM, and 2Shape. The sample had 45° and 90° angles, a 5 mm radius, and 1.5 mm diameter channels. In order to achieve the fracture, Özyürek et al. monitored the cycles, determined when it would happen, and subsequently rotated the files within the canal. Of the files tested, Reciproc Blue had the greatest resistance to fracture for canals with a 90´ curvature; however, for canals with a 45´ curvature, there was no discernible difference. Cyclic fatigue resistance was lowest for Wave One Gold, highest for HyFlex EDM, and lowest for Reciproc Blue. Compared to the 2Shape file, the HyFlex EDM file had a higher number of cycles to fracture for both 45¸ and 90´curved canals.[15]

Shen et al. (2018) looked at the effects of cyclic fatigue on torsional failure and torsional preloading on fatigue resistance. The files were tested with HyFlex CM and EDM, and the tip size was 40 points. In order to determine the impact of torsional preloading on cyclic fatigue, extra files were subjected to testing with several degrees of torsional preloading (0%, 10%, 15%, 2%, or 25%). Additionally, canals with a 60¸ angle of curve and 5mm radii were also evaluated, with a synthetic St. Other files were tested for torsional strength using a 3mm file tip, while files that had undergone various cycle preloading processes were examined for torsional fatigue. Thanks to this, the impact of cyclic preloading on torsional fatigue may be investigated by Shen et al. When it came to torsional and fatigue resistance,

Hyflex EDM files were superior to Hyflex CM files. Cyclic fatigue was reduced by torsional preloading, however there was no correlation between cycle preloading and torsional fatigue.[16]

Keskin et al. (2017) tested 18 Reciproc, WaveOne, and WaveOne Gold samples for cycle fatigue resistance. The 18 instruments were tested using a 3 mm axial movement amplitude dynamic model in an artificial canal that had a 5 mm radius, 1.5 mm inner diameter, and 60 º angle of curvature. The greatest tolerance to cycle fatigue was WaveOne Gold, which showed no effect from interrupted reciprocation action. Interrupting reciprocation weakens Reciproc and WaveOne's resistance to cycle fatigue failure.[17]

Room temperature cycle fatigue resistance was investigated by Scott et al., 2019 for EdgeFile X1, WaveOne Primary, and WaveOne Gold. The instruments were tested in a synthetic canal that had a 3mm radius and an angle of 60º. The findings showed that in terms of cycle fatigue resistance, EdgeFile X1, WaveOne Gold, and WaveOne main were in that order: highest, medium, and lowest. The results demonstrated that the cyclic fatigue behavior of reciprocating instruments was unaffected by martensite phase change.[18]

In order to find the dynamic cycle fatigue resistance of several materials, Keles et al. (2017) submerged them in a mixture of distilled water and 5.25% NaOCl for 5 minutes. These materials included Reciproc Blue R25, WaveOne Gold Primary, One Shape, and WaveOne Primary. A man-made stainless-steel channel with a radius of 5 millimeters and an angle of curvature of 60 degrees was used to test the devices. After varying immersion times—ten minutes in distilled water at 37°C, 60°C, ten minutes in NaOCl water at 37°C, and ten minutes in NaOCl at 60°C—ten files from each system were evaluated. Immersing all cases in 60°C NaOCl significantly reduced the cycle fatigue resistance, with the exception of Reciproc Blue R25, which demonstrated the best results overall.[19]

Hyflex Cm, FlexMaster, Vortex Blue, and TruNatomy were the four models examined by Elnaghy et al. (2020) for their torsional resistance and cycle fatigue ratings. We held a 5 mm file tip in our hands to test the torsional fatigue. In a simulated canal with a 5mm radius and a 90º degree angle of curvature, the twenty files from each system were tested at room temperature. In a dynamic cycle fatigue model, the files were subjected to axial movement with an amplitude of 3mm using the Instron device until they failed. When comparing the two, Hyflex CM demonstrated superior resistance to cyclic fatigue, while FlexMaster excelled in torsional resistance.[20]

Three controlled memory files—EdgeFile, One Curve, and HyFlex CM—were compared to one file produced from M wire—ProTaper Next—in terms of dynamic cycle fatigue resistance at both room and intracanal temperatures by Topçuoğlu et al. 2020. Instruments may be spun freely in an S-shaped stainless-steel channel to measure how long it took for them to shatter. When tested at room temperature, ProTaper Next exhibited much reduced cycle fatigue resistance; nevertheless, when tested at intracanal temperature, EdgeFile and One Curve fared better than the other two controlled memory files. The cycle fatigue resistance of each file declined as the canal temperature rose.[21]

The cycle fatigue resistance of TRUShape and Hyflex EDM was tested by Arias et al. 2020 following gamma irradiation and autoclave sterilization. Twenty-two tools were autoclave sterilized and forty-four were gamma irradiated for every file. There were twenty-two additional files that were autoclaved separately, and twenty-two that were not irradiated or otherwise affected. The three-millimeter-radius, sixty-degree-curvature three-metal-pin simulated canal was used in the room-temperature experiment. Across the board, Hyflex EDM demonstrated superior resistance to cyclic fatigue. Hyflex EDM's cycle fatigue resistance was unaffected by additional autoclaving or gamma radiation, in contrast to TRUShape, which showed the opposite impact.[22]

Blue heat-treated instruments were tested for cycle fatigue endurance at various temperatures by Vieira et al. 2021. All three groups that participated in the trial utilized endodontic instruments from Voltex Blue 40\0.04, Recipro Blue 40/0.06, and XI Blue 40/0.06. A range of temperatures, from 20 to 37 degrees Celsius, were applied to the uniformly dispersed dirt. The RB instruments showed considerably higher cyclic fatigue resistance than the VB and XB instruments at the temperatures that were tested ($p<0.001$).[23]

The effects of Hyflex EDM, twisted files, and Proteper Gold fracture cycles were documented by Khandagale et al. 2021, along with the length of the artificial canal's curved portions. A metal block with a simulated canal 8 mm in radius and with a 90° angle of curvature was used to test sixty NiTi rotary instruments, each measuring 25 mm in length. An equal number of Hyflex EDM, Twisted files, and ProTaper Gold devices were utilized (20). After Twisted and Protaper Gold files, Hyflex EDM ranked third for cycle fatigue resistance.[24]

Various nickel-titanium rotary systems were heat-treated at intracanal temperature, and Güneç et al. 2021 tested their cyclic fatigue resistance. The following data points were documented: the following parameters for an artificial stainless steel canal: intracanal temperature (35.5°C), inner diameter 1.5 mm, angle of curvature 60°, and radius of

curvature 2 mm: OneCurve, VDW.ROTATE, Typhoon, Hyflex EDM, and EndoArt Gold and Blue rotary files (#25/0.06), with a sample size of fifteen. The EndoArt Blue group had the longest mean time to fracture compared to the other groups. Here are the items in question: Typhoon, EndoArt Gold, Hyflex EDM, OneCurve, and VDW ROTATE.[25]

Research by Fiad et al. 2021 examined the effects of sterilization on the cyclic fatigue resistance of rotary files made by OneCurve and Reciproc Blue. Thirty files were utilized from each system for each cyclic fatigue test. It was found that out of thirty rotary files, ten were used immediately following sterilization, ten after three cycles, and ten after six cycles. We conducted the cycle fatigue testing using a static model and specialized equipment. A stainless-steel artificial canal measuring 5 mm in radius and 60° in angle was created to allow the instruments full rotational freedom within the device. Reciproc Blue offers superior resistance to cycle fatigue as compared to One Curve. Some files are unaffected by cyclic fatigue due to sterilization, whereas others are negatively affected.[26]

Using two types of files, Khaleefah et al. 2021 compared the cycle fatigue resistance of gold-tech files (such as ProTaper Gold F2 and WaveOne Gold Primary files) with M-Wire-tech files (such as ProTaper Next X2 and WaveOne files). For this inquiry, forty files were utilized, which were then divided into four categories. Stainless steel artificial canals with a 5 mm radius were used in the cyclic fatigue tests conducted by the cyclic loading testing machine. The canals were curved at 45°. We timed the duration until each rotating device broke after we had given it an opportunity to spin and reverse. It was found that WaveOne files had greater cyclic fatigue resistance than Protaper Next files, and that gold alloy files had better cyclic fatigue resistance than M-Wire alloy files.[27]

The cycle fatigue resistance of new TruNatomy Files was tested using stainless steel blocks with three distinct curved artificial grooves, in comparison to ProTaper gold, HyFlex EDM, and Reciproc blue (Reddy et al. 2021). One indicator of cyclic fatigue is the NCS, or number of separation cycles. The cycle fatigue resistance of Hyflex EDM and Reciproc blue were similar, however the maximum was found in TruNatomy files.[28]

Conclusion

Research comparing the cyclic fatigue resistance of several endodontic rotary instruments has shown how important material choice, design, and treatment protocols are for increasing longevity. Among the tools evaluated, HyFlex EDM consistently showed the highest cycle fatigue resistance, thanks to its distinctive spark-machined surface and innovative production methods that utilize electrical discharge machining (EDM). Despite displaying noticeable torque resistance and varying fatigue resistance across different conditions, the HyFlex EDM files outperformed instruments such as WaveOne Gold, Reciproc Blue, and ProTaper Gold in several tests, including curved canal simulations, temperature variations, and sterilization techniques. Several environmental elements, including as temperature, irrigant solutions, canal curvature, and other similar variables, have been shown to have a substantial impact on the efficiency of these devices, according to the research.

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