"Stress is the Fuss" -- Understanding Cyclic Fatigue

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ABSTRACT:

Background: Fracture in the rotary nickel-titanium (NiTi) instruments have been classified into two Cyclic fatigue fracture and torsional fracture. Fracture in an endodontic instrument can also occur by a combination of both. Clinically, NiTi rotary instruments are subjected to both torsional load and cyclic fatigue, and the present review focusses on the Cyclic fatigue fracture occuring in the endodontic instrument.

Methods: Several methods have been used to test the cyclic fatigue resistance in endodontic instruments because there is no specific standardised test to measure the cyclic fatigue resistance in endodontic instruments.

Results: Cyclic fatigue fracture occurs in the endodontic instruments without any specific signs of plastic deformation. There are various devices to test the cyclic fatigue resistance in the endodontic instruments but there is no data about the fit of the instrument in the various assemblies being used to test the cyclic fatigue resistance. Also, the bending properties of different files will make them follow different trajectories, thus making the comparisons and the results biased.

Conclusion: The clinical relevance of the results of the devices used to test the cyclic fatigue resistance in endodontic instruments is difficult to assess because the condition in-vitro is completely different from the condition in-vivo. Cyclic fatigue is very low in the instruments that are made with M-wire technology compared to the regular SE-wire endodontic instruments. Endodontic instruments, which are manufactured by a twisting technology, have much higher cyclic fatigue resistance compared to the instruments manufactured by grinding.

Keywords: Cyclic fatigue, Instrument fracture, Instrument separation, Torsional fatigue, Rotary instruments.

INTRODUCTION

Root canal shaping is one of the most important steps in root canal therapy.[1] Proper and safe cleaning and shaping of root canals depend on the mechanical behavior of endodontic instruments.[2] Traditionally, root canal shaping has been carried out by using stainless steel hand files. However, during the 1980s nickel-titanium (NiTi) files were introduced. NiTi files offer significant advantages such as the ability to maintain the original root canal shape and prevent the creation of irregularities (eg, zipping, ledge formation, and perforation). NiTi file systems vary in terms of cross-section, blade, and pitch designs and taper angles.[1]Insufficient knowledge of instrument characteristics may lead to procedural errors (ledge and transportation) and/or fracture of the instrument in the canal.[2]

The unexpected failure of nickel–titanium (Ni–Ti) rotary instruments inside the root canal during root canal treatment is a matter of serious concern, as these instruments can undergo fracture within their elastic limit without any visible sign of previous permanent deformation.[3] Fracture of instruments used in rotary motion occurs in two different ways: fracture caused by torsion and fracture caused by flexural fatigue.[4] The fracture that occurs when an instrument tip or another part of the instrument is locked in a canal while the shank continues to rotate is the Torsional Fracture and this occurs at the tip of the endodontic instrument when the elastic limit of the metal is exceeded by the torque exerted by the handpiece. Instruments that fracture because of torsional loads often carry specific signs such as plastic deformation.[4] On the contrary, the fracture that occurs because of metal fatigue when the instrument does not bind in the canal, but it rotates freely in a curvature, is the Cyclic fatigue fracture. This occurs due to the tension/compression cycles which generate at the point of maximum flexure until the fracture occurs.[5]When the instrument is rotating in the canal, the half of the instrument shaft on the outside of the curve is in tension, whereas the other half of the instrument shaft on the inside of the curve happens to be in compression. This repeated tension-compression cycles, increase cyclic fatigue of the instrument over time and may be an important factor in instrument fracture.[5] The present review will be focussing on the cyclic fatigue fracture in endodontic instruments.

DISCUSSION

Material fatigue appears to be an important reason for the separation of rotary instruments during clinical use. Peng et al classified most of the fractured instrument analyzed as flexural failure, implying fatigue being the predominant mechanism for material failure. In a related study, Cheung et al reported that the great majority (93%) of instruments appeared to have failed because of flexural fatigue. This might be explained as follows: first; fatigue-crack growth rates in NiTi alloys have been reported to be significantly greater than in other metals of similar strength . Thus, once initiated, these micro cracks can propagate very quickly leading to instrument fracture.

Whereas, In another study carried out by Sattapan et al it was reported that torsional fracture occurred in 55.7% of all fractured files, whereas flexural fatigue occurred in 44.3%.[4] These results indicated that torsional failure, which may be caused by using too much apical force during instrumentation or by other contributing factors such as the pre-existing size of the canal, occurred more frequently than flexural fatigue, which may result from use in curved canals. American National Standards Institute/American Dental Association (ANSI/ADA) specification. No. 28 prescribes tests to measure strength under torsion and flexibility of stainless steel hand files.[5]

Various types of devices used to test cyclic fatigue

In the endodontic literature available for fatigue testing of NiTi rotary instruments, the instruments are subjected to rotational bending to measure the fatigue resistance. Different devices use different geometric curvatures in which the rotary instruments are subjected to rotation until fracture.

Several studies have used artificial canals that were constructed by bending glass or metal cylindrical tubes with different inner diameters and point of maximum curvature and using different radii and angles of curvature. There were certain limitations using these devices. Since each instrument has its own specific tip size, taper, design, pitch length, and morphologic and geometric features, thus, it will follow its own trajectory in tubes that do not sufficiently constrain the shafts of the instruments, especially the smaller ones. If the files are not constrained in a specific trajectory, the bending properties of different files will make them follow completely different trajectories. Therefore the results and comparisons may be biased using these devices.

In order to overcome these limitations, Cheung et al constrained the instrument into a curvature using three stainless steel pins.

Other studies have used an artificial canal that consisted of a grooved concave tempered steel block and a convex tempered steel cylinder, which when held and fixed together, guaranteed the curve of the instruments . There are a variety of devices and methods that have been used to investigate in the cyclic fatigue fracture resistance of NiTi rotary endodontic instruments. There is no data about the fit of the instrument in the various assemblies being used to test the cyclic fatigue resistance. As the instrument is likely to be fitting loosely, the description of the radius of curvature in those studies is likely to be overstated (ie, the file was actually bent less severely than reported, adding a variability in the amount of flexural stress).

Also, the bending properties of different files will make them follow different curvatures, thus making the results and comparisons biased.

Effects of raw material and rotational speed of the endodontic instruments on the cyclic fatigue resistance

Generally, the cyclic fatigue property of rotary instruments is determined by geometric design, surface condition (roughness and residual stress), and microstructure. According to the latest study on the metallurgical characterization of M-Wire by Alapati et al , M-Wire contains deformed and microtwinned martensite, R-phase, and austenite. M-Wire instruments have shown to have superior resistance to fatigue-crack initiation compared with regular Super-Elastic (SE) wire files. The files manufactured with M-wire technology (martensitic variants) have better reorientation capability because of the lower symmetry of the monoclinic crystal structure of martensite than the cubic crystal structure of austenite. These also have a property of austenite to martensite phase transition.Therefore during bending rotation fatigue or cyclic fatigue, these show better accomodation of deformation by phase transition mechanism and favourable reorientation of localized martensite variants.This effectively reduces the time of formation and accumulation of microstructural defects such as surface irregularities or subsurface voids in which fatigue cracks could nucleate, making these more superior to the regular SE files.

The instruments made of M-Wire exhibited a significantly higher cyclic fatigue life (150% better) compared with those made of regular SE-wire.[6]

Influence of manufacturing methods of endodontic instruments on the cyclic fatigue resistance

Most nickel-titanium (NiTi) rotary endodontic instruments are machined bygrindiing although some are produced by twisting the alloy after heat treatment. According to the manufacturer, Twisted File instruments are produced by a proprietary process of heating and cooling of NiTi that leads to a molecular structure known as the R phase. In this state, NiTi can be twisted, resulting in instruments with optimized properties. The alloy in the R phase displays super elasticity and shape memory, allowing the production of more flexible instruments compared with their ground counterparts[7]

Comparison of the mechanical properties of rotary instruments made of conventional nickel-titanium wire, m-wire, or nickel-titanium alloy in r-phase

The M-Wire alloy has physical and mechanical properties that can render endodontic instruments more flexible and more resistant to fatigue than those made from a conventional NiTi wire. According to some authors, the most important parameter influencing the torsional failure of endodontic instruments is the angular deflection at failure and not the maximum torque. During clinical use, the angular deflection at failure may act as a safety factor with regard to torsional fracture. The higher the angular deflection at failure that an instrument can tolerate, the higher the elastic and plastic deformation. the results showed that the K3XF instrument, which is made of NiTi alloy in R-phase, had the overall best performance in terms of flexibility, angular deflection at failure, and cyclic fatigue resistance. The instrument ProFile Vortex, which is made of M-Wire alloy, did not show the expected results in the flexibility and cyclic fatigue tests. In addition to the alloy from which the endodontic instrument is manufactured, design and dimensions are important determinants of its mechanical performance.[2]

CONCLUSION

The clinical relevance of the results of the devices used to test the cyclic fatigue resistance in endodontic instruments is difficult to assess because the condition in-vitro is completely different from the condition in-vivo. In all these tests, only one characteristic of the instruments (bending failure) is extraploated whereas When the instrument in in the canal, then a number of other factors also come into play to cause failure like torsional fatigue. yclic fatigue is very low in the instruments that are made with M-wire technology compared to the regular SE-wire endodontic instruments. Endodontic instruments, which are manufactured by a twisting technology, have much higher cyclic fatigue resistance compared to the instruments manufactured by grinding.

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