Tikrit Journal for Dental Sciences 11(1) (2023) 69-75
ISSN:2073-1213
https://doi.org/10.25130/tjds.11.1.8

IRAQI Academic Scientific Journals

Tikrit Journal for Dental Sciences
https://tjds.tu.edu.iq

Influence of Anatomical Root Factors on Cyclic Fatigue Resistance of Heat Treated NiTi Instrument: A Review

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Article Info:
-Article History:
-Received: 23/8/2022
-Accepted: 11/9/2022
-Available Online:
Jun, 2023

Keywords:
Cyclic fatigue, Angle and radius of curvature, Double curvature, Location of curvature.

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Abstract

Endodontic treatments have been improved over the last decade by the use of nickel titanium (NiTi) alloys. NiTi instrument had shape memory and superelastic properties which made the instrument more flexible, so the treatment quality was enhanced by eliminating the procedural errors. Although the numerous benefits of the NiTi instruments, the fracture was the most frequent failure that may be happened during its use due to flexural (cyclic) or torsional fatigue. Various thermo-mechanical heat treatments have been applied to NiTi instruments to improve fracture resistance and clinical performance. Several parameters influenced the fatigue resistance of NiTi files, and the most important factor that affected the likelihood of NiTi instrument fatigue was the root canal shape. Data collected of 100 papers from the Goggle scholar and ScienceDirect database. After excluding 60 unrelated papers, this review of 40 included related studies aims to evaluate an overview of the anatomical root-related factors affecting the cyclic fatigue of heat-treated NiTi instruments. Concluded that the separation rates of file increased when the radius of curvature decreases and when the angle of curvature increased. Canals with the double curvatures increase the risk of cyclic fatigue. Also, the resistance to cyclic fatigue of NiTi files was affected by the canal curvature position, with a short failure life coronally. So even in the improvement of wire metallurgy and designs of instrument, the anatomy of canal still impact on the cyclic fatigue and should be considered during preparation especially with the new concept of minimally invasive endodontic treatment.

Introduction:

Nearly thirty years ago, nickel-titanium (NiTi) rotary files were produced for the first time, and they improved root canal instrumentation (1). They have taken control of most of the iatrogenic instrumentation issues that come with stainless steel (S.S.) files (2). Superelasticity of NiTi alloy allows for fully repairable deformation up to 8% strain, in comparison to 1% in S.S. (3). Despite the numerous advantages of the NiTi endodontic instrument, the fracture was the most frequent issue that happened when using it due to flexural (cyclic) or torsional fatigue, or even a mixture of the two (4). Cyclic fatigue has been reported to occur without any prior evidence of irreversible deformation (5). This can happen when an instrument was rotated within a curved canal and exposed to excessive periods of compression-tension cycles at the peak of the canal curve. But, when the instrument's tip binds inside the canal and the file was rotated beyond the elastic limit of the NiTi alloy, torsional fatigue was developed (6). Utilizing microscopic and fractographic examination, researchers discovered that cyclic fatigue failure caused 66–93% of the rotary instrument fractures, while shear failure caused 7–34% (7). Over the last decade, NiTi rotary files have seen significant advancements to improve fracture resistance and enhance clinical performance. Manufacturers have used a variety of treatments on NiTi instruments to improve their elasticity and breakage resistance, including electro-polishing of the surface. Recently, NiTi alloy has undergone thermo-mechanical treatments to improve the structure and transitional performance of the file, which affects the physical properties of the rotary file and the mechanical properties improvement, as well as the addition of a new alloy to NiTi metal or the creation of cross-sectional new designs for the same purpose (8,9). The root canal morphology, in addition to the metallurgy of the file was influenced by the probability of NiTi instrument fatigue (10). The metallurgical features of the instrument, as well as its kinematics, alloy, operational setting, and other aspects, all had a role in the cyclic fatigue resistance (11). But there were several criteria related to the certain properties of curved canals including; the angle and radius of curvature, the canal shape, and the location of the curvature, so during a fatigue test, these considerations should be taken into account (10). The instrument stress was mostly affected by the radius and location of curvature (12). The complexity of the root canal has a negative impact on the instruments resistance to fatigue (13). This review article evaluated an overview of the anatomical root-related factors affecting the resistance to cyclic fatigue of NiTi instruments.

Root canal anatomy related factors

The cases with complex morphology of the canal had a higher likelihood of file fatigue (14). The fractures were mostly common in molar teeth than premolars or anterior teeth. Additionally, the fracture in the mesiobuccal root of molars teeth occurred more than in other roots. The abrupt curvature of these roots was the most likely cause (15).

Angle and radius of curvature

Pruett et al. (1997) method used these parameters radius (r) and angle (a) of a root canal to describe its curvature. Throughout the long axis of the canal, two lines were drawn to establish these parameters; one line has been drawn in coronal part and another line was drawn in apical part. Each of these lines had a point at which the canal curve started (point A) and the canal curve ended (point B). The tangents of these points form a circle demonstrated the canal's curved segment. The angle drawn by the arcs of the circle and previous points represented the degree of curvature as shown in Fig. 1. They discovered that the instrument stress and strain increased, and the fatigue resistance declined when the radius of curvature decreased. Due to the independence of these two variables, it was theoretically feasible to obtain the two canals that have similar angle but with various curvature radii or the reverse (16). The cyclic fatigue of the file was higher when the curvature angle was large. The rotary file failure was mostly influenced by the radius of curvature when other root canal anatomy-related factors were evaluated (17). The canal curvature radius was more important than the curvature angle itself. When the radius of curvature decreased, the rate of file separation increased (18). But, when the angle increased, especially above 30°, there seems to be an increase in the chance of fracture (19). Even though two canals share the same angle of curvature, the radius of curvature may differ, indicating that certain curvatures were sharper than others. The radius and angle of curvature characteristics were independent in this way (20). Wan et al. (2011) found that the 90° curvature angle produced the least number of cycles to fatigue (NCF), while the highest NCF were obtained at a 45° curvature NCF of OneShape and WaveOne files systems (21). Short radius of curvature, large curvature angles, and long arc lengths were the geometric features of canals that raised the possibility of fatigue (22). The ProGlider, PathFile, HyFlex GPF, and Scout Race instruments showed a reduction in NCF at a curvature radius of 3 mm compared to a curvature radius of 5 mm (23). The lifespan of the instrument was decreased by an increase in the severity of the curvature's angle and radius (24). The combined effect of the heat-treated instrument's angulation and narrow curvature radius reduced their fatigue resistance (25). Severely curved canals were defined as having S-shaped curvature with a 25–70° radius of curvature. The materials, manufacturing methods, and designs of cross-section of the NiTi instruments all had an impact on the cyclic fatigue of those instruments. The fatigue resistance frequently showed lower values at 60° than at 45° of curvature, which mean the NiTi files' fatigue resistance was lowered when the angle of curvature was bigger (26).

Shape of curvature (single and double curvatures)

Double curvatures could be present in the same canal at the same time, depending on the clinical condition. Approximately all canals exhibit secondary curvatures according to a radiographic study looking at the frequency and extent of canal curvatures (27). The NCF value had been lower in the double curved canal than in the single curved canal in both the apical and coronal curvatures. As a result, the canals with double curvatures increased the risk of cyclic fatigue (13). The S-shaped root canals can be problematic and difficult to perform; they have at least two curves, with the apical curve being particularly susceptible to anatomical variations, working length loss, and the possibility of file separation. Endodontic files that have been utilized in clinical settings have broken, and fatigue has been identified as the main cause (28). The extension of the curvature was certainly one of the most essential features that could cause the fatigue of the instrument. One of the most difficult clinical cases was the "S" shape canal (29) as shown in Fig. 2. Furthermore, such curvatures were difficult to identify in standard radiographs but can be seen from a distal or mesial view (30). In comparison to the mesial root of the mandibular molars and the distobuccal root of the maxillary molars respectively, there were recorded rates of 30 % to 40 %, and 35 % to 59 %, of S-shaped canals (31).In comparison to single curvature canals, double curvature canals indicated a substantially more demanding and challenging morphology, where the resistance to fatigue may be impacted when canal curvature increased (32).

Location of curvature

An early study found that the cervical curvature was predominant (45.2%) in the posterior teeth, while the apical curvature was predominant in the anterior teeth (33). The location of the curvature along the canal was the significant parameter influencing the mechanical behavior of an instrument by affecting the stress-strain capability of the instrument. The canal's curve location can be changed, and it was placed either at end or at middle position (12). It was accepted that the more risk of endodontic instrument breakage occurs in complicated root canal morphology (34). Additionally, compared to the middle and coronal parts of the canal, the apical part of the canal had a greater probability of file separation (35). The greatest diameter of an endodontic instrument shaft leads to the greatest tension or compression (near the center of the curve) and the greatest intensity of the stress resulting in the smaller NCF (36). Arias et al. (2012) investigated the resistance to fatigue of Reciproc and WO files in the canals with curvatures located at (5 and 13) mm from the file tip. They found that the curve coronally located (at 13 mm) significantly decreased the resistance to fatigue of these reciprocating files (37). In contrast, in a dry environment inside a curved canal, the difference in fatigue resistance between continuous rotating files with an apical curvature and those with a midroot curvature. This investigation found that Mtwo and BioRace had much less fatigue resistance in midroot-curve canals compared to apical-curve canals (36). In a double-curved artificial canal, Al-Sudani et al. (2016) examined the resistance to fatigue of ProTaper Gold and Pathfile NiTi rotary files; they showed a higher resistance to cyclic fatigue of PTG in coronal curvature (38). To prevent flexural fatigue from concentrating on a particular area of the instrument, it was typically advised that the instruments should be routinely repositioned in an axial direction over time as opposed to remaining in a fixed place within a curved canal. In addition, once-used instruments should be discarded, especially after using in extremely complicated and calcified or steeply bent canals (39).

Conclusion:

According to the evaluated studies, the separation rates of file increased when the radius of curvature decreased and when the angle of curvature increased. Also, canals with double curvatures increase the risk of cyclic fatigue. The resistance to cyclic fatigue of NiTi files was affected by the canal curvature position, with a short failure life coronally. So even in the improvement of wire metallurgy and designs of instruments, the anatomy of canal still impacts on the cyclic fatigue and should be considered during preparation especially with the new concept of minimally invasive endodontic treatment.

Acknowledgements:

Special thanks to Mustansiriyah University (www.uomustansiriyah.edu.iq), Baghdad, Iraq for it is support in the present work.

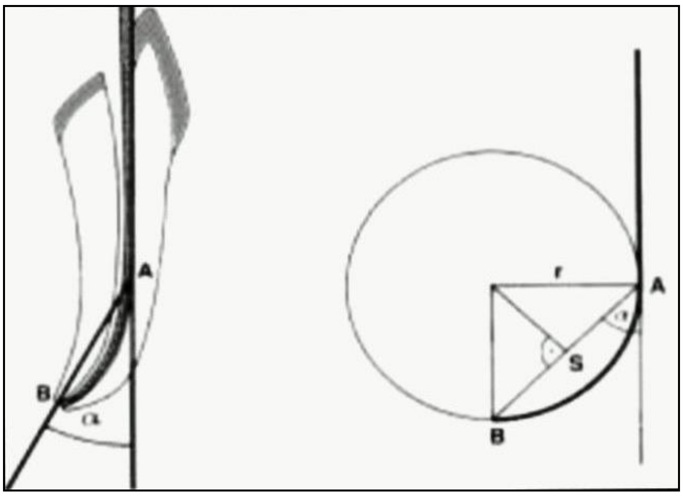

Figure (1): Drawing of canal curvature (Pruett et al., 1997).

Figure (2): Single and double curved canals (Machado et al., 2014).

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