Review

Factors influencing NiTi endodontic file separation: A thematic review

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Abstract

Nickel-titanium (NiTi) file separation during endodontic treatment is an undesirable event. This phenomenon needs to be understood by knowing the factors influencing fracture in endodontic files. There is a large amount of literature where these factors and their influence have been studied, increasing the knowledge about the mechanisms involved, mainly related to wire technology, file shapes and geometry, operator manipulation, the anatomy of the root canal, and the irrigation and sterilization processes. As many factors are involved, the complexity of the fracture phenomena increases and the isolated correlation of one factor with the file fracture becomes a small part of comprehending the separation phenomena. This thematic review aims to compile important reports from 2014 to 2022 on the factors influencing NiTi file separation. The information obtained was classified into wire technology, file geometry, operational aspects, irrigation and sterilization, and anatomy. For this purpose, the Scopus, Web of Science and ScienceDirect databases were consulted using a search string. Filters were applied to consolidate the final set of relevant papers covering the subject of factors influencing endodontic file separation. It was found that the fracture of NiTi files incorporates different mechanisms that operate simultaneously during the endodontic procedure and strongly affect the instrument performance. The collected information promotes good practices to prevent file separation.

Keywords: endodontics, nickel-titanium alloy, dental instrument separation, thematic review

Introduction

Nickel-titanium (NiTi) files are motorized instruments used for root canal preparation in endodontic procedures. NiTi is an alloy with superelasticity (SE) features, allowing the instrument to adapt to the anatomy of the root canal and avoid irregularities such as zipping, ledging, and perforation.[1,2] Aspects such as motorized operation and procedural times have improved due to the SE properties of NiTi.[3] However, the relationship between cutting efficiency, heat treatment, rotary motion, cross-section, and tapper design, is complex and needs to be studied and more thoroughly understood.[4]

Even though NiTi files have shown outstanding properties superior to stainless steel and other materials, there are still some issues that need to be solved to improve NiTi file reliability in endodontic practice. The superelastic behavior is caused by deformation that induces phase transformations. The material goes from austenite (A) to the R-phase (R) and martensite (M). Martensite gives the material superior strain properties. Once the effect causing the initial deformation (stress) is reversed, a reverse M–A transformation of the alloy and the original shape can be achieved depending on the amount of M-phase developed in the material.[5]

One of the most critical issues in NiTi file use is separation, which entails instrument fracture inside the root canal, causing severe health and economic complications for patients and ethical problems for professionals. Some file manufacturers and professionals consider that using one file per root canal or tooth can ensure instrument structural integrity during an endodontic procedure.[6] The consequence of this approach is an increase in costs, which can affect access to treatment. Also, in the literature, instrument separation has been reported in the first file usage.[7]

Another proposed approach is improving the material properties to promote better performance. There has been a relevant development in NiTi wire technology obtained through machining and heat treatments.[8] Resistance to fracture was improved, allowing the instrument to be used repeatedly. However, the dentist still does not know when a file will fracture.[9] Also, the lack of adequate diagnostic techniques to determine the instrument's condition for further use and if continuing to use the file is safe indicates the need to understand the failure mechanism and predict when the file separation may occur. Many efforts are being made to develop systems to evaluate the usability of endodontics files.[10–13]

Table 1. Representative papers about endodontic file separation

Study	Year	Review subject	Article type
Çapar and Arslan[15]	2016	Presents an overview of the advancements in instrumentation kinematics and the effect of instrumentation kinematics on the root canal shaping procedures and instrument performance.	review
Ya et al.[19]	2016	To evaluate the defects and their frequency of occurrence in WaveOne files after being used in patients.	in vivo
Ahn et al.[20]	2016	The comparison of the kinematic effect of NiTi instruments with a reciprocating and continuous motion for cyclic fatigue resistance, shaping ability, apical debris extrusion, and dentinal defects or cracks.	review
Alsilani et al.[21]	2016	The comparison of the available reciprocating systems – Reciproc and WaveOne.	review
Ferreira et al.[16]	2017	The correlation between different movement kinematics and the cyclic fatigue resistance of NiTi rotary endodontic instruments.	review
Peláez Acosta et al.[22]	2017	To verify the torsional strength of files manufactured with CM-wire and compare them with the values presented by files manufactured with superelastic (SE) alloy.	in vivo
Gavini et al.[23]	2018	Characteristics of NiTi alloys. Influence of metallurgical and mechanical properties of these instruments. Movement types.	review
Cassimiro et al.[24]	2018	To verify the generation of defects in dentin, generated by root canal instrumentation.	ex vivo
Tabassum et al.[5]	2019	Discusses different phase transformations and heat treatment that NiTi instruments undergo.	review
Hülsmann et al.[14]	2019	Summarizes the currently available evidence to point out the different outcomes from static vs. dynamic tests, and to assess whether cyclic fatigue tests provide valuable data and information for clinical practice.	review
Leal Siva et al.[25]	2020	The evaluation of the influence of the autoclave sterilization procedures on the cyclic fatigue resistance of heat-treated NiTi instruments.	review
Leal Siva et al.[26]	2020	Comparison of cyclic fatigue resistance. Different techniques were used to check the design and composition of the files, and transformation temperature similarities.	ex vivo
Kermeoglu and Abduljalil[27]	2022	To examine the impact of irrigants, with and without sterilization, in ProTaper, Wave One Gold and Reciproc files on cyclic fatigue resistance.	in vitro
Orozco-Ocampo et al.[28]	2022	To identify typical failure mechanisms for rotatory and reciprocating files. To summarize the standard mechanical tests for endodontic files and the characteristics of their assembly.	review
Avcil et al.[29]	2022	Martensitic transformation temperature. Wear mechanism and friction coefficient monitoring.	other
Dragoni and Scirè Mammano[30]	2022	To study the high-performance shape memory effect of NiTi wires under constant stress loading. Linear stress–strain variation.	other

Computational simulation and experiments have been essential research tools for determining the mechanical properties of the NiTi alloy. Using these tools, optimizing endodontic variables such as the axial movement of the instrument,[14] types of rotational motion,[15,16] the instrument geometry (size, taper, pitch, cross-section, among others),[17] rotational speed,[18] duration of usage,[19] among others, have been attempted. However, factors that cannot be controlled, like root canal curvature and the human operator's axial movements, can affect the predictability of the model.

Several literature review articles were identified through a search on fracture mechanisms and factors that influence endodontic file separation. Some are shown in Table 1.

This paper presents a compendium of factors reported from 2014 to 2022 that influence the fracture of NiTi endodontic files during root canal instrumentation through a search of relevant literature. The papers reviewed were focused on describing and analyzing the effects of metallurgical and mechanical features of the alloy used for files on instrument fracture.[5,27] Features included rotational movements (kinematics) during instrumentation,[15] comparison between files with the same kinematics but different manufacturers,[20] static vs. dynamic root canal instrumentation,[14,14,31] and autoclave sterilization.[32] For the total number of papers consulted, we found 4 reported as in-vivo experimentation, 60 as in-vitro, and 8 ex-vivo studies. The remaining papers are reviews, computational simulation results, and other studies. Factors related to file separation were classified into wire technology, file geometry, operational factors, irrigation and sterilization, and the root canal anatomic factor.

This thematic review process is based on the need to contribute to the understanding of endodontic file fracture by identifying factors related to this phenomenon. It also aims to provide the reader with a document that summarizes and discusses, in a holistic approach, the factors that influence the separation of endodontic files so that it can be used as a base document for future research on the subject.

Methodology

Some questions were formulated to focus the search for scientific information and subsequently filter the documents found according to the topics of interest of this review.

Q1: Which factors are involved in the fracture of NiTi endodontic files?

Q2: What information is found in the literature to prevent failure?

The Scopus, Web of Science and ScienceDirect databases were consulted to find the most relevant work reports on endodontic file separation. The methodology followed for the literature review includes steps proposed by Kitchenham and Charters.[33] Initially, the search term "endodontic file" was used in all fields, resulting in high results. For that reason, other terms related to file separation were added to narrow the search. The search string and document selection process are shown in Fig. 1.

The search was limited to research articles and conference papers from 2014 to 2022. Some databases did not allow a unique search for the entire search string; for those cases, the search had to be performed separately. Next, all data was combined from each database and repeated results were removed. This search yielded 851 unique results. The paper titles were scrutinized to verify that the documents were related to fatigue, failure, and separation of NiTi endodontic files. From this process, 245 items remained. Next, the abstracts, discussions, and conclusions were reviewed. Comparative studies and articles focused only on a descriptive approach to the performance of one manufacturer compared to others were excluded, resulting in 151 remaining research papers. After reading the complete articles, 100 of the most representative documents for the identified factors were used.

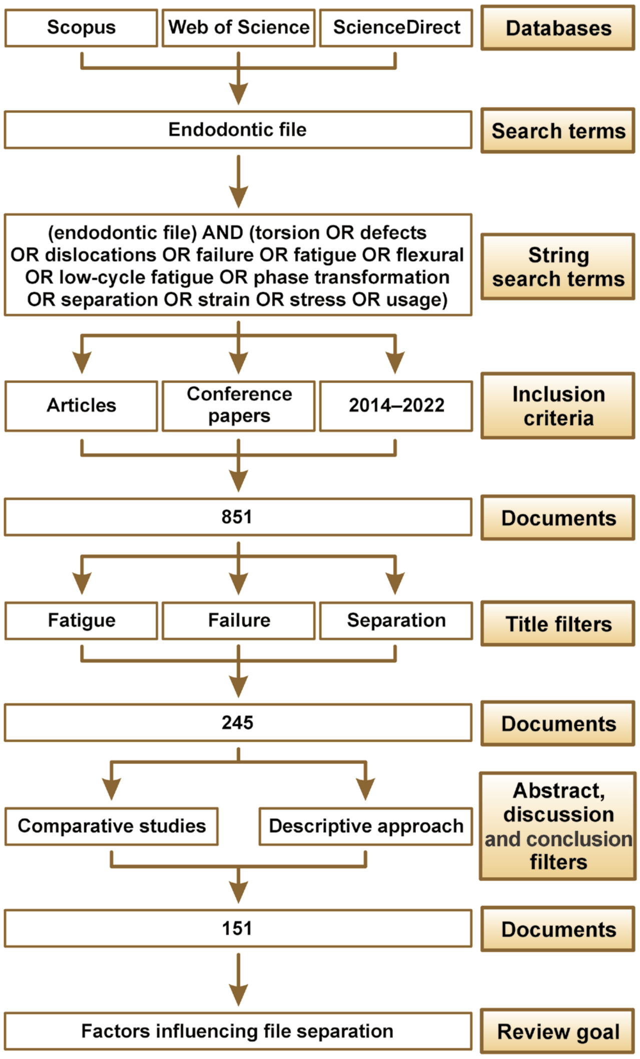

Fig. 1. Flow chart for the document search and selection

Fracture of NiTi endodontic files

File fracture inside the root canal during an endodontic procedure is related to two failure mechanisms: torsional fracture and fatigue fracture. The first mechanism presents when the file tip becomes locked in the canal wall, and the torsional strength of the instrument is exceeded.[34,35] Torsional stress can lead to plastic deformation of the file, which, depending on axial movements, will result in unwinding in the most affected section of file.[32] The second mechanism is due to the flexion–compression cycles. This may occur when file rotation in a curved canal causes one section to simultaneously be in tension while the other is in compression. Repeated cycles of the NiTi files will lead to fatigue failure by work hardening-softening of the material's microstructure by internal stress accumulation. This hardening-softening leads to a loss in flexibility and increased brittleness.[36,37] The number of cracks generated on the surface where the stress concentration is higher than the cohesion forces during flexion causes crack propagation.[38–41]

The files are subjected to torsional and fatigue forces during endodontic procedures. From the fatigue contribution to failure, Braz Fernandes et al.[8] found that independent of the geometry, sections near the midpoint of the curved section of the file inserted in the root canal were subjected to higher stress levels during instrumentation due to the occurrence of maximum deformation amplitude.[40,42] Finally, file fracture can be caused by the accumulation of effects, which have been reported to occur at this file segment.[43,44]

Several studies have focused on establishing each fracture mechanism's role (torsion and/or fatigue) in file separation.[4] Jamleh et al.[45] found that fatigue impacts the hardness and elastic moduli of endodontic files, reducing these properties by 17% and 13% during torsion, respectively, showing the dominant effect of fatigue on file separation, as has been reported by other authors.[19,46] Sattapan et al. found that in 378 NiTi endodontic files analyzed after clinical use, 50% showed visible defects; of these files, 21% were fractured.[47] They also identified that 55.7% of these separations were due to torsional loads and the remainder to bending loads. Torsional failure was associated with apical forces and bending fatigue with canal curvature.[47] Others have reported that torsional stress affects the fatigue resistance of the materials and vice versa.[34,44,48] Several studies have concluded that crack nucleation occurs at the blade surface and propagates to the inner region, exhibiting an opening crack propagation Mode-I (tensile), revealing the capital importance of rotational bending versus torsional loads in crack propagation.[18,49]

Separation during an endodontic procedure primarily depends on the different NiTi phases present in the material. As previously mentioned, NiTi files exhibit 3 phases,[5,50] and the R-phase is an intermediate or a pre-martensitic phase preserving the features of its SE behavior.[8,51] Also, in A-R-M transformations, the austenite elastic properties are promoted at low deformations but the strain increases.[48,52] From the microstructural perspective, the NiTi phase transitions lead to the formation of a branched morphology attributable to martensite.[51] Crack propagation occurs through the interfaces of this branched structure, resulting in crack propagation. A higher dissipation of energy and a slowdown of the speed at which cracks grow at equal stress intensity levels is related to the austenite phase.[50,53,54]

This behavior implies that when the file is in the martensite phase, it is more resistant to fatigue failure, as has already been reported.[50,55,56] Joviano Pereira et al. found that file separation occurs at ultimate tensile strength in the martensite phase.[57] These authors were implying complete transformation to the martensite phase during deformation.[57] Cyclic phase transitions (A-R-M and M-R-A) may be accompanied by residual stress accumulation through dislocations and internal stresses, which entails a reduction of stress required for martensite transformation, resulting in work softening.[58–60] Even though deformed NiTi files exhibit good fatigue resistance, other types of loads (e.g., torsion), cracks, or plastic deformations, can also cause fractures.[32,56] The highly-stabilized martensite SE is limited by plastic deformation. The plated structure is promoted, and further strains lead to fractures.[56,61]

Table 2 presents the 5 principal factors that affect the separation of endodontic files.

Figure 2 shows the number of papers reviewed on file separation factors. In this case, the most studied factors are operational factors and loads. Additionally, it is observed that the factor on which the least literature has been generated is related to anatomical factors.

Wire technology

It is widely accepted that the properties of the material are directly related to its performance. Specifically, endodontic instrument fracture depends primarily on the mechanical properties exhibited by the elements that the tool is comprised of and on the crystalline state (phase) of the NiTi file. NiTi alloy endodontic files performed better than those fabricated with stainless steel because of the superelastic behavior of the NiTi austenitic phase. This property is associated with high deformation of the material through the strain-induced transformation from the austenite to the martensite phase and the recoverable form by reverse phase transition.[50,52] Superelastic behaviors are attributed to the conventional NiTi (austenitic) alloy. At room temperature, austenite NiTi files exhibit low flexural fatigue resistance compared to martensite files due to their high hardness.[40,41,93] It has also been discovered that files with a high martensite phase content exhibit increased flexibility, crack growth reduction (energy dissipation in a branched structure), and better fatigue resistance.[26,40,53,93]

Table 2. References per factor from the literature review

Factors influencing file separation	References
Related to wire technology: – NiTi phase transformations; – types of wire	16,30,32,36,37,39,43,45–47,49,51,52,57,62,63,65–70,71
Related to file geometry: – cross-sectional area; – core mass; – pitch length; – helical angle; – taper	8,17,34,51,53,57,60–63,69–78
Related to operational factors and loads: – types of movement (continuous rotation and a reciprocating motion) – handling (dynamic (pecking) and static immersion movements) – flexural fatigue – torsional fracture – fracture mechanisms	16,17,18,29,32,36,46,60,65,69,81–83 8,18,32,34–37,40–42,44,48–54,56,57,59–61,68–70,82,83,87–89
Related to irrigation and sterilization: – corrosion effects of the irrigant – thermal effects of sterilization	25,27,36,41,61,64,72,73,77,88–92
Related to the anatomic factors: – root canal shape and size	37,40,59,75,92

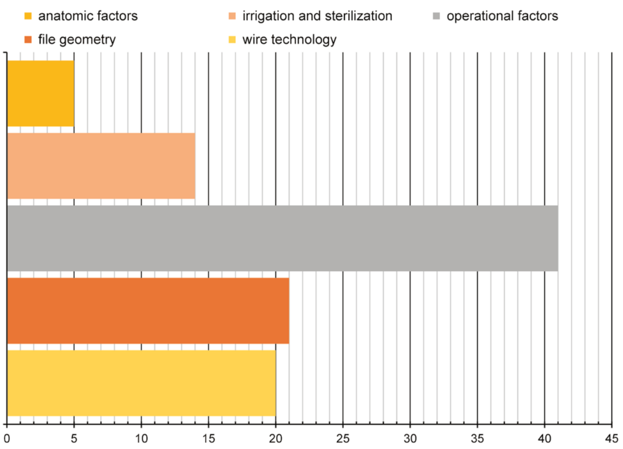

Fig. 2. Documents per factor related to file separation

Even though endodontic instrument manufacturers have secret treatment procedures, wire technology has evolved through the years from conventional NiTi wires to M-wire® and Controlled Memory or CM-wire, among other similar technologies. NiTi wires with total R- or martensite phases enhanced with thermo-mechanical treatments, are an excellent material to fabricate endodontic files.[34] Regarding the thermo-mechanical treatment, the austenite finish temperature (A_f) is shifted to higher values, inducing the presence of stable R- and martensite phases in NiTi files at room (RT) and body temperatures (BT), thus causing improved flexibility and resistance to cyclic fatigue during use.[52,62,69,94] As A_f is higher than RT and operational BT, the performance of the endodontic file is improved due to the martensite and R-phases. The closer A_f is to RT and BT, the file exhibits higher stiffness and less fatigue resistance when used in root canal instrumentation because of the contribution of the austenitic portion in material.[38]

The differences between wire technologies are attributed to the amount of stable R-phase (or martensite) induced during thermomechanical pre- and post-treatment. This is related to the A_f and machining techniques, considering that endodontic files with M-wire technology have an austenite phase with a small R-phase content.[50] Pirani et al. conducted studies to compare WaveOne (M-wire) to ProTaper F2 files (conventional NiTi).[51] The metallographic analysis showed that M-wire technology consists of a high portion of symmetrically twinned martensitic phases (microcrystalline grains) compared to conventional NiTi files.[54] Also, multiple initiation cracks were found in the WaveOne instrument, which was not the case for the ProTaper F2 file. The R-phase and crack initiation were assumed to be responsible for the incremental fatigue of the WaveOne file.

M-wire files have also revealed a high ultimate torsional strength due to their ductility[48,63] as compared to RaCe, ProTaper F2 (both conventional NiTi), and Twisted files (R-phase). Here, it is important to note that R-phase content in M-wire instruments can vary among manufacturers. Some files will exhibit properties more similar to conventional NiTi than others, depending on this R-phase/austenite ratio. R-phase endodontic instruments, compared to conventional NiTi and M-wire technologies, were studied by De Arruda Santos et al.[50] In this study, the uniaxial tensile test revealed that the R-phase had the lowest elastic modulus and plateau stress among all measured samples, which can be beneficial during root canal instrumentation as the instrument will not exhibit resistance to following canal geometry and hence prevent shaping defects like flanges and zipping. A consequence of this capability is that the original shape cannot be recovered, which could be achievable by post-thermal treatment. Finally, this study reported that the R-phase file also showed low bending stress and improved fatigue resistance.

Regarding austenite transformation temperatures, CM technology wires generally have the highest A_s and A_f temperatures.[50,52] CM-wires have exhibited similar properties of R-phase materials, like the remaining deformed shape and the subsequent recovery after thermal treatment,[50] pre-bending capability,[42] and a superior proportion of martensite microstructure.[37] These properties lead to a predominance of martensitic behavior, such as high flexibility, low bending resistance, and higher resistance to fatigue over conventional NiTi and M-wires.[38,66,69] Even though the martensite phases improved fatigue resistance, CM-wire files have shown low torsional resistance compared to those fabricated with M-wire.[17] Pedullá et al. compared the torsional strength and the number of cycles to fatigue (NCF) of ProTaper Next (M-wire) and HyFlex CM (CM-wire).[44] They concluded that while HyFlex CM files had higher NCF than ProTaper Next, torsional resistance was higher for the M-wire technology files.[44] This behavior was also found by Peláez Acosta et al., who found that even if crack ramification in a branched martensitic-like structure can be beneficial for energy dissipation and, hence, fatigue resistance, different types of loading applied to these multiple cracks could weaken the material.[22]

Alcalde et al. found that ProDesign R files (CM-wire) exhibited an evident angular distortion (plastic deformation), indicating that the instrument is close to fracturing.[17] Finally, manufacturers have developed different machining methods to conventional grinding, like electro-discharge machining (EDM) of CM-wires. Files manufactured by the EDM method are composed of martensite and a predominance of R-phase, enhancing flexibility and ductility and improving fatigue resistance.[95] Different studies have shown improvement in NCF of EDM compared to CM-wires of around 700%,[67,70] regardless of geometrical effects like cross-sectional shape and area. HDM files have also exhibited higher independence to temperatures than CM files, allowing their performance in a broader range of temperatures than seen in root canals.[38]

File geometry

Endodontic instruments possess highly complex geometrical features. It is well known that variations in shapes are highly diverse between manufacturers. File properties such as flexibility,[37,73] torsional strength[77,79,96] and fatigue resistance[17,65,97] are dependent on file size, taper, flute depth, pitch length, cross-section, helical angle, thread size, and cross-sectional shape. Regarding their size, in general, those files with a lower cross-sectional area at the maximum curvature point presented low stress levels and hence higher resistance to fatigue due to improved flexibility.[81,98] This factor can even be more crucial than wire technology for specific files.[60] On the other hand, smaller areas lead to low torsional strength values.[19,66] Regarding the shape of the cross-section, those with lower mass content in the core area also had improved fatigue resistance, as reported by Bhatt et al.[54] and supported by other authors.[41,62]

The cross-sectional shape and axial off-centering influence the times the file touches the root walls. High contact can lead to dentinal defects,[24,99] stress distributions along and across the file,[8,60,74,75] and influence cutting efficiency.[76] Also, the number of threads, commonly proportional to helical angle and inversely to pitch length, has been shown to influence endodontic file performance.[77,80] Peláez Acosta et al. reported that the shortest pitch (high number of threads) exhibited higher torsional resistance in files with a triangular convex cross-sectional area.[22] This effect was also reported by Oh et al. in V2H and NRT files.[77] Al Raeesi et al. explained improving cutting efficiency, relating a decreased pitch length with incrementing cutting edges.[80]

Operational factors

Regarding the dependence of endodontic file fractures on how the canal instrumentation is executed, two main factors can influence the instrument durability. First, two types of motor movements can be used in an endodontic procedure: a rotary and reciprocating motion. Over the last decade, reciprocating movements have been widely demonstrated to have notable advantages over rotary movements in avoiding severe damage to the files. Reciprocating movements avoid engaging the tip. This reduces torsional stress,[51] decreases the frequency of occurrence of one cycle during rotation,[84] releases accumulated stress,[62] and reduces torsional strength.[83] Since endodontic instruments have spiral geometrical configurations, the pull-in effect (screw-in effect or taper lock) can lead to plastic deformations as the endodontist applies a contrary force to counter it. In this sense, reciprocating motion eliminates taper lock as it does not rotate continuously as the instrument is inserted into the canal.[37,66] Pirani et al. claimed that this type of movement is suitable for specific wire technologies.[51] However, other works have not found any relationship between the type of movement and fracture resistance of endodontic files, nor in cutting ability.[76]

Second, the device engages in static and dynamic motions during instrumentation. Dynamic methodologies (such as the widely known pecking motion) refer to the in-and-out motion (at a specific amplitude). This methodology allows the distribution of stress to be generated along the file length instead of concentrating it on a limited section, avoiding stress levels that can cause plastic deformation (unwinding) or fracture. This stress distribution is through flexion in the curved segments or contact between the device and dentine surface.[8,37,86]. At the same time, the file is inserted into the root canal, which exhibits benefits over static motion (the file is inserted with zero amplitude) to prevent file fracture during operation. Concerning the frequency of the pecking motion, Zubizarreta-Macho et al. found that a low-frequency pecking motion increases fatigue resistance compared to a high-frequency motion.[85]

Regarding the amplitude of the pecking motion, two effects compete when the pecking amplitude is varied. On the one hand, a large pecking amplitude is recommended as it allows for stress distribution along a greater possible length of the file.[84] However, this large amplitude also increases screw-in forces during instrumentation, causing possible unwanted penetration beyond the apical foramen.[35,86] On the other hand, small amplitudes will concentrate torsional and flexural stress on specific file segments, reducing screw-in forces. In this sense, the pecking amplitude must be such that it does not allow the concentration of stress or high screw-in forces.

Further research must be carried out to determine optimal amplitude values. High forces when the file is inserted into the canal can produce high torque, leading to root dentin damage and instrument fracture.[35,37] Also, significant diameter differences between sequential files can severely affect the instrument's integrity and generate high-stress accumulation.[79] Finally, highlighting the critical role of the specialist when making decisions to ensure the instrument's suitability during the endodontic procedure is essential.[19]

Irrigation and sterilization

During canal root instrumentation, irrigation with NaOCl is widely used to achieve tissue dissolution and disinfection. The exposure of the endodontic file to this solution is well known to induce micro-pitting by removing Nickel from the surface in a corrosion process by the aggressive Cl-O ions.[72,88,90] This process has a detrimental effect on the instrument, reducing its fatigue resistance when highly stressed parts of the file and crack initiation zones on the surface are corroded.[41,91]

Many endodontists reuse endodontic files as a common practice, but sterilization procedures are implemented to eliminate cross-contamination between patients. Sterilization involves (among other aspects) the application of thermal treatment to the instrument, which strongly affects its composition and structural and morphological features. For this reason, it is essential to know how these changes can affect the instrument performance and, ultimately, its failure. As a favorable factor, it has been found that sterilization at certain temperatures and certain wire technologies have been found to improve flexibility/ductility and strength by rearrangement of the crystalline structure and by releasing crystalline defects and strain hardening.[77,89,98,100] However, repeated sterilization cycles can produce unfavorable effects on endodontic files, such as alteration of their chemical composition at the surface by oxidation and micro-pitting, inducing changes in morphological features, and reducing its cutting efficiency by 50%.[88] In this respect, after conducting studies on the sterilization of endodontic files, some authors have concluded that there is a strong correlation between sterilization processes and fracture resistance.[101,102] However, considered that few endodontic NiTi file manufacturers suggest the possibility of repeated use of the instrument. A single file must be developed, facilitating timesaving and possible use without adverse consequences.

Anatomic factors

As has been established, the endodontist can manipulate or modify certain factors to prevent file separation during root canal instrumentation. However, one factor that cannot be controlled by the professional and strongly influences instrument fracture. Root canals possess essential parameters such as curvature angles and radius, which have been found to influence an instrument's lifespan.[37,59,75,92] As the angle of curvature or the radii of curvature increases, the time before file fracture also increases, which is related to deformation amplitudes in the zone of maximum deformation.[40,75] In this sense, when considering the size, shape, and number of root canals, endodontists must determine suitable tools and methodologies to perform the procedure and prevent file separation.

Conclusions

Several aspects of file separation are related to mechanical causes of file fracture, such as the shape and dimensions of the file, loads applied during the operation on the endodontic instrument, and the manipulation of the instrument. Other significant factors are irrigant solutions, sterilization by autoclaving, anatomical features, and the alloys used for the files.

Research continues to improve the properties of the alloys, mainly the interaction between hyperelasticity and fatigue strength, file geometry, and unique designs offering particular characteristics that reduce friction loading during the cutting process. Concentration limits have been established for irrigants, as their effect on files is known. More studies have yet to be performed on the thermal effects on the strength of materials during sterilization.

Material compliance and stiffness, operational temperatures, cutting efficiency, stress distribution in the file, surface modifications, corrosion, and recrystallization processes in post-heat treatments all contribute to the final performance of the file, implying a high complexity of failure and difficult predictability of the instrument.

Another factor to be considered is the selection of appropriate files. Various options, such as wire technology, type, size, and shape of the files, manipulation techniques, exposure to corrosive environments, and sterilization processes, should be based on the specific anatomical features of the root canal.

What properties of endodontic files and work conditions that preclude file separation, including how many times the files can safely be reused while maintaining appropriate properties, has been the subject of significant research in the dental literature. However, the causes of instrument fracture remain incomplete and further research is needed. To avoid unexpected file separation, the use of the endodontic file must follow the manufacturer's indications regarding the permissible number of sterilizations.

Many of the articles reviewed were laboratory studies focused on determining the performance of files subjected to different factors that can cause a fracture. The clinical relevance of these studies is difficult to assess because the experiments were done under conditions significantly different from those in the oral cavity.

It seems necessary to standardize different methodologies to compare the factors that statistically cause fracture failures of files.

Ethics approval and consent to participate

Not applicable.

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Consent for publication

Not applicable.

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