Factors influencing the life span of modern root canal instruments – a literature review

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INTRODUCTION

The main objective of endodontic treatment is to obtain complete debridement of infected tissues from the root canal complex and to prepare the system to meet biological and mechanical requirements. The second objective is to protect the original design of the root canal system and to preserve the size, shape and position of the apical foramen.[1]

The contour of the endodontically-prepared root canal should be that of a smooth funnel, with the smallest diameter at the root apex and the largest at the orifice. The completed funnel allows the complete removal of infected tissues and the subsequent placement of obturation materials.[1,2]

Cleaning and shaping of long, thin and curved root canals challenge the clinician's endodontic skills.[3,4] These difficulties predispose to instrument fracture, ledging, and blockages resulting from insufficient irrigation, and may result in "dentinal mud", root perforations, apical zipping, elbowing, strip perforations and accidental extrusion of debris.

Studies by Lim and Stock and by Mckendry and others have shown that procedural accidents are not always due to an error on the part of the clinician, and can occur no matter how precise the cleaning and shaping technique or the endodontic device/system.[5,6,7,8,9]

ROOT CANAL INSTRUMENTS

The endodontic hand instruments of the early 1900s were made from stainless steel and carbon steel. Carbon steel was abandoned because of its poor corrosion resistance. Stainless-steel hand files were inherently stiff and of limited flexibility. The discovery of nickel-titanium memory alloy in the early 1960s changed endodontics forever. This material has been widely used throughout the health sciences because of its excellent biocompatibility, shape memory effect, and superior elasticity.[10]

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ACRONYMS

EDTA: Ethylenediaminetetra-acetic acid

PrP: Prion Protein

TSEs: Transmissible Spongiform Encephalopathies/prion diseases.

VHN: Vickers Hardness Number

Nickel-titanium alloy has unique qualities – mainly increased strength together with the enhanced elasticity. Root canal reamers and files with four-fold and even higher tapers are now available, which makes them completely different from earlier instruments.[11,12,13] The introduction of nickel-titanium to endodontics made it possible to produce consistent and efficient canal shaping with fewer instruments.[13,14,15]

Nickel-Titanium

Civjan, Huget and DeSimon initiated the use of nickel-titanium in dentistry.[16] The first K-bladed file was created by machining nickel-titanium orthodontic arch wire to produce a fluted instrument.[11]

Later, Nitinol SE 508 was used for the ProFile endodontic system (Dentsply/Maillefer, Ballaigues, Switzerland). The raw wire undergoes a series of procedures to obtain the desired design and properties. Cold manipulation is carried out to achieve the correct cross-sectional diameter before the wire undergoes thermo-cyclic treatment under strain. The wire blanks are then fashioned to create the rotary endodontic instruments.[17]

The nickel-titanium alloy is super elastic and can return, within considerable limits, to its original shape. Once the material is stretched, however, certain changes can take place within the austenitic structure. A martensitic transformation ensues and, if the instrument is then stretched beyond its elastic limit, the structure will rupture and lead to instrument failure.[18] Despite this particular risk, the material has been widely used by both general clinicians and specialist endodontists worldwide.

Compared with stainless steel endodontic instruments, nickel-titanium products endure more torsional stress before failure and are reported to be three times stronger.[11] Their introduction in endodontics has led to a reduction in clinical chair time, more accurate cleaning and shaping of root canal systems, and a minimising of procedural risks.[11,19,20]

Nickel-titanium rotary instruments also provide the potential to clean and shape the root canal system much faster than do stainless-steel hand files.[21] Further, the use of rotary nickel-titanium endodontic instruments has been shown to be associated with a higher success rate than seen in those treatments performed exclusively with stainless-steel hand instruments.[22]

The super elasticity of nickel-titanium endodontic instruments confers a major advantage in their ability to clean and shape curved root canals. Stainless-steel instruments larger than size 30 are more rigid and robust and are, therefore, prone to procedural accidents in curved canals.[23]

Early studies proved that the use of nickel-titanium endodontic instruments produced more centred and properly tapered preparations of root canals than did stainless-steel instruments.[24] Numerous other studies have confirmed the results.[25,26,27] Crown-down preparation techniques were introduced in combination with rotary nickel-titanium instruments of greater taper, which proved to produce root canal preparations with more predictable outcomes and a reduced risk of procedural accidents.[28,29,30,31]

M-Wire

M-Wire, a new type of nickel-titanium wire, has been developed by a series of proprietary thermo-cyclic processing procedures.[32] This material has showed great promise in reducing the failure risk of endodontic instruments through cyclic fatigue.

The first rotary M-Wire endodontic instruments developed included the GT Series X and the ProFile Vortex systems (Dentsply, Tulsa Dental, Tulsa, OK).[33,34,35,36,37] According to the manufacturers, nickel-titanium endodontic instruments created with M-Wire are even more flexible and resistant to failure than those made from traditional nickel-titanium alloy.

Alapati, Brantley and Lijima conducted a study to determine the metallurgical characterisation of M-Wire and found that the material contains all three crystalline phases (deformed micro-twinned martensite, R-phase, and austenite).[38] M-Wire has a higher Vickers hardness number (VHN) than the super-elastic nickel-titanium material Nitinol and, therefore, a higher micro hardness. A value of 385 VHN was found in M-Wire compared with a value of between 312 and 376 VHN for Nitinol rotary endodontic instruments.[39]

A reduction in grain size of metals and alloys leads to increased strength in the new material.[40,41] Ye and Gao speculate that the superior mechanical qualities and increased resistance to torque and mechanical wear and tear of the M-Wire nickel-titanium alloy can be ascribed to its 100-nanometre martensite grains.[32]

The most recent introduction of M-Wire in endodontics is the WaveOne Endodontic System (Dentsply/Maillefer), where a single instrument is used in a reciprocating movement (150° counter-clockwise movement and 30° clockwise) to prepare a root canal system.

R-Phase

SybronEndo Corporation (SybronEndo, Orange, CA) has adopted a different approach to the manufacturing process of nickel-titanium endodontic instruments and have designed the Twisted File. The manufacturing technique involves a combination of heat treatment and twisting of a ground blank nickel-titanium wire.

A raw nickel-titanium wire is selected in its austenite crystalline structure and, by means of heating and cooling procedures, a completely new crystalline phase of the alloy is created, referred to as the "R-phase". In this phase the nickel-titanium alloy cannot be ground and twisting is the only way it may be processed. Hence the Twisted File (SybronEndo) is created by twisting the R-phase wire into the desired shape, heating and cooling it to maintain this shape and then converting it back to its austenite crystalline structure. The structure is super elastic once the stress relief procedure is completed.[42]

The development of these manufacturing techniques and processes was in the endeavour to find a way of enhancing super elasticity and increasing the cyclic fatigue resistance.[43] Larsen *et al.* (2009) demonstrated in their study that the unique design of the Twisted File in conjunction with the use of the R-phase nickel-titanium alloy did indeed contribute to an increase in resistance to cyclic fatigue.[34]

Another advantage of the Twisted File is that the instrument is not created by means of a grinding process, which causes micro-fracture points in the crystalline structure along the complete length of the file. Rather, the new process leads to the formation of the R-phase of the nickel-titanium alloy, which preserves the crystalline structure and increases the resistance to fracture and instrument failure.

Gambarini *et al.* (2008) compared the performance of the size 25, .06 taper Twisted File with that of the K3 (SybronEndo) (size 25, .06 taper) instrument with regard to cyclic fatigue.[42] The authors concluded that together with the new way of creating the enhanced nickel-titanium material R-phase, the Twisted File concept produced instruments which are far superior regarding fatigue resistance.

Vortex Blue

Vortex Blue (Dentsply, Tulsa Dental) is a recent development that will, according to the manufacturer, improve fracture resistance and cutting ability, have superior flexibility relative to previous nickel-titanium rotary systems and will enhance the ability to more precisely shape a centric root canal preparation. The development involves a state-of-the-art proprietary thermo-mechanical process to manipulate the nickel-titanium alloy.

Vortex Blue instruments are produced through a proprietary manufacturing process which results in the formation of an oxide surface layer having a unique 'blue colour', different from other nickel-titanium instruments. The titanium oxide (including anatase and rutile) has a hardness of between 5.5 and 6.5 on the Mohs scale and in the range of 620 to 970 VHN on the Vickers scale.[44]

The formation of the titanium oxide surface has increased failure resistance by providing more hardness to the instrument, which at the same time has more flexibility than the ProFile Vortex instrument (Dentsply, Tulsa Dental). Gao *et al.* (2012) proved that rotary endodontic instruments manufactured with Vortex Blue alloy showed superior elasticity, hardness and resistance to fracture over conventional nickel-titanium instruments.[45]

Controlled M-Wire (CM-Wire)

In October 2011, Typhoon Infinite Flex nickel-titanium rotary endodontic system (Clinician's Choice Dental Products, New Milford, Connecticut) was launched. This endodontic instrument is manufactured using controlled-memory (CM) nickel-titanium wire.

Shen *et al*. (2011) demonstrated that CM-Wire was 300% to 800% more resistant to fatigue failure than conventional nickel-titanium.[46] These authors also noted that the instruments showed many more crack origins than did conventional instruments, but the increased fatigue resistance can be ascribed to CM-Wire's bulk mechanical properties and increased fatigue crack thresholds.

A major advantage of the Typhoon CM file (Clinician's Choice Dental Products) is that its memory has either been removed or controlled by a special thermo-mechanical process. This remarkable product differs from any other nickel-titanium rotary endodontic instrument because the instrument can be pre-curved and bent to adapt to root canal curvature. This feature allows the instrument to follow the root canal anatomy without creating unwanted, disproportionate lateral forces on the canal walls. Pre-curving of the instrument also facilitates working on teeth with limited access (second and third molars) and allows management of root canals with ledges.[47]

The design includes a non-cutting tip. The instrument 'follows' the root canal, preserving tooth structure as less is removed during cleaning and shaping.[47] Traditional nickel-titanium instruments have perfect memory, and their use causes a straightening of the root canal curvature.[47] The Typhoon CM instrument will not attempt to straighten in curved root canals and hence should not alter original root canal anatomy. The Typhoon CM file has increased torsional strength and increased resistance to cyclic fatigue and is more likely to unwind than separate.

INSTRUMENT FRACTURE

There are undeniable advantages in the use of nickel-titanium rotary instruments in endodontics, but the operator does face the risk of instrument fracture, an unfortunate but persistent problem in root canal preparation, especially in curved canals. Fracture of an endodontic instrument inside the root canal remains a serious problem and can alter the prognosis,[3,4] impeding the likelihood of reaching the final goal of the planned treatment.[1,48]

Unfortunately, conflicting results have been reported on the clinical significance of an endodontic instrument separating within the root canal and on what the long-term result would be were the instrument tip left inside the root canal system. It is sometimes nearly impossible to remove the fractured segment. Evidence shows, however, that in certain cases (teeth with necrotic pulps or teeth with periapical lesions) it will be more traumatic and unfortunate if the instrument separates, as the chances of successful healing will be reduced.[49]

The tooth undergoing root-treatment has a poorer prognosis if the endodontic instrument separates in the apical third of the root canal or beyond the root canal curvature, as it will become more difficult to remove. The greater the curvature of the root canal, the more difficult will become removal of the sliver.[50,51,52,53] If a high risk is involved (possible root perforations or root fractures), the clinician would be well advised to exercise great care when attempting removal of the segment. It may be prudent to accept that these fractured endodontic instruments should be left alone.[54]

With continuous rotation inside the root canal the file encounters torsional and bending stress, which causes intense compression and flexion forces within the file. This can lead to structural fatigue and fracture.[55,56] Bending stress and cyclic failure seem to be more prominent in curved root canals while torsional stress and torsional failure are more prevalent in straight canals.[57] The more a rotary nickel-titanium endodontic file is placed under working stress, the greater the pressure on the durability. The risk of failure increases.[58,59,60]

Torsional stress

Torsional stress can be described as the amount of stress generated within the instrument when it engages the root canal wall or when the operator subjects the instrument to increased apical force. This is the main cause of instrument fracture. The instrumentation of root canals of smaller diameter generates more torsional stress during the cleaning and shaping procedure than when dealing with root canals of larger diameter.[61]

The clinician can control the manipulation of the endodontic instrument and therefore can reduce the intensity of the torsional stress.[61]

Bending stress

Bending stress can be described as the force generated within the nickel-titanium alloy by rotating an instrument in a curved root canal. This will result in repeated compression and flexing at the point of maximum curvature – a very destructive form of loading of the instrument, despite the fact that nickel-titanium has superior elasticity and that there is no binding to the canal wall.[56]

Larger and more tapered endodontic instruments will encounter much greater bending stress in curved root canals than will an instrument with a smaller diameter and taper.[62] Larger taper reamers require more material and more detailing in the manufacturing process, unfortunately rendering the instrument liable to earlier failure if it is subjected to flexion stress.[63,64]

Bending stress is a very important factor affecting fatigue within the nickel-titanium file and it may be an unexpected problem if the root canal anatomy is unknown.

FACTORS INFLUENCING INSTRUMENT FRACTURE

Instrumentation technique

Research has concluded that the less knowledge and experience the operator has, the higher the incidence of instrument fracture.[65,66] With ongoing use of a particular rotary nickel-titanium instrument, the operator's tactile sensation tends to improve and he or she will then be able to sense a rise in torsional resistance and the risk of taper lock.

The results of these studies have led to an effort to improve operator proficiency and thereby to reduce the risk of instrument separation. Operators need to be properly trained in the use of nickel-titanium rotary endodontic instruments and to acquire operating experience to avoid procedural mishaps, including fractures of the files.[3,65,67]

At present, a number of guidelines are available for operators on the relatively safe use of endodontic instruments.[68] These include: examining instruments before and after use to detect any deformations (the flutes of the instrument should be evenly aligned); not using endodontic instruments in dry root canals; following the manufacturer's instructions carefully; and always avoiding excessive forces, especially apical pressure.

Marending, Lutz and Barbakow (1998) and Mandel *et al.* (1999) found that the frequency of instrument fracture not only varied between different operators but also at different times with the same operator during the sequence of cleaning and shaping.[3,69] Recently, a collaborative study conducted by endodontists from four different countries concluded that the most important factor influencing the incidence of endodontic file separation and formation of defects on the instruments was the competence and technique of the operator. Some of the participants in the study used the endodontic instruments for a limited number of times, while others used them until defects were observed.[70]

Number of uses

There is a very close relationship between the number of rotary cycles the nickel-titanium file performs and the working stress created within the file.[56] The more cycles the endodontic instrument endures, the greater the working stress and the higher the risk of fracture.[58,59,60] Used instruments have a higher risk of failure and fracture than those used for the first time.[71,72]

Sotokawa (1990) suggests that the clinician adopt a system for replacing used nickel-titanium instruments when an allocated predetermined number of uses has been reached.[73] It is more beneficial to discard used instruments after a certain number of uses than to take the risk of persevering until the instruments show signs of actual deformation.[18]

To achieve the most predictable safety it has been suggested that a rotary nickel-titanium endodontic instrument should be used only once.[74] In that particular study, 786 once-used instruments were examined and only 14% showed visual signs of fatigue and distortion and only seven instruments fractured.

All the modern rotary nickel-titanium endodontic instruments are expensive and at least three to four are usually required in the treatment sequence. A single-use multi-purpose instrument would therefore be very beneficial for the general dentist as well as the endodontist, requiring only the one device in the sequence. However, success would depend on whether all the mechanical and biological endodontic objectives could actually be achieved with a single instrument.[75]

Instrument manufacturing

Most clinicians are unaware of the exact composition of the alloy and of the manufacturing methods for each nickel-titanium endodontic instrument. The production process of most involves grinding the material rather than twisting the metal.[76] Occasionally a clinician may unknowingly use a faulty instrument.[77,78,79]

Analysis of the microstructure and surface of brand new nickel-titanium instruments reveals some interesting findings, including: distortions in the lattice structure of the nickel-titanium alloy; inconsistency in the micro hardness; marks left during the machining and milling of the alloy during the production phase; and finally the presence of micro cracks on the surface.[80,81,82]

Occasionally nickel-titanium rotary endodontic files can separate at a point below their elastic limit as a result of factors inside the material, called "slip bands".[83] These are microscopic mechanisms within the material which allow grains to slide over each other, increasing the chances of fatigue and fracture.

Some studies have confirmed that electro-polishing the instrument after it has been manufactured may increase its resistance to failure and provide superior working properties.[84,85,86] Electro-polishing can be described as the process whereby a very thin layer of the instrument is removed by placing the instrument in a strongly ionic solution through which is passed an electric current. Electro-polishing adds a few very important characteristics to the instrument, including graining the boundaries, creating superior mechanical properties and reducing dimensions. The process also removes pitting and surface irregularities caused by machining the material, which can otherwise act as centres for fracture formation.[87]

The ProFile (Dentsply/Maillefer), EndoWave (J Morita Corporation, Osaka, Japan) and RaCe (FKG, La-Chaux De Fonds, Switzerland) rotary nickel-titanium endodontic systems are examples of instruments that undergo the electro-polishing technique.

Tooth anatomy

A very important factor to consider is the individuality of dental anatomy. Root canal morphology and anatomy are different for every tooth. Variations in root canal anatomy that present hidden challenges to the clinician include: merging canals, curving of canals, and recurving and dilacerating/dividing canals. The original anatomy of the canal before instrumentation is a factor that influences bending stress on the file and has nothing to do with the clinician.

Reports from research show that separation of endodontic instruments occurs more often in molars.[88,89] The mesial roots of the mandibular molars are those most likely to cause instrument separation and, more specifically, the apical third of the root canal compared with the middle or coronal third.[50,51,89] A fact that clinicians should keep in mind additionally is that two canals being present with the same angle of curvature does not necessarily mean that they possess throughout the same radii of curvature. This means that some root canals describe curves that are sharper than others and pose more challenges to clean and shape.[90]

Pressure on the instrument

The more apical force used by the operator, the greater the risk that the nickel-titanium instrument will encounter taper lock, undergo structural failure and fracture.[61,63] Endodontic instruments can be described as 'active' or 'passive', the former having blades for the cutting and removal of tooth structure while passive endodontic instruments have a radial land between the cutting edge and flute.

Active instruments are able to remove more dentine aggressively, faster and more efficiently, while passive instruments produce a scraping or burnishing action and therefore remove dentine at a much slower rate, reducing the tendency to change and straighten the original canal morphology.[91] The natural tendency for the operator will then be to apply more apical force to proceed deeper and faster and this will eventually lead to torsional fracture.[92]

Torque-Controlled Motors

As mentioned previously, torsional and bending stresses play a crucial role in instrument failure, but there is another factor, namely, torque, that influences the stress placed on the endodontic instrument. In the clinical situation where an endodontic motor is used that generates a high degree of torque, it is very easy to exceed the fracture limit of the endodontic instrument. In combination with torsional and bending stresses, a high degree of torque can increase the risk of instrument failure substantially if great care is not taken.

A possible solution would be to use an endodontic motor with a torque-control function and to determine a maximum permissible torque limit for each instrument. In the event of the instrument tip binding into the root canal, torque-control motors will stop and then start rotating in the opposite direction.[93,94] This auto-reverse function is an excellent safety measure, especially when the operator uses a low maximum torque endodontic system like the ProFile (Dentsply/Maillefer) and Greater Taper (GT) (Dentsply/Maillefer) rotary nickel-titanium systems.

However, there is one important consideration of which the clinician needs to be aware. A certain amount of force is required to stop the instrument from rotating, to disengage the instrument from its original path, and then to rotate it in the opposite direction. This 'effort' is then stored in the instrument memory. With each cycle having auto-reverse activated, more and more memory is stored leading to a reduction in its lifespan.[95]

Rotation rate

A study by Gabel *et al*. (1999) and Yared *et al*. (2001) demonstrated that the failure of ProFile rotary endodontic instruments was related to the rotational speed of the instrument.[65,96] A lower rotational speed produced a lower risk of instrument separation.[65,96] Consensus has been reached between most manufacturers that rotational speeds ranging from 150 to 350 rotations per minute (rpm) should be used for the cleaning and shaping procedure.

The higher the rotational speed, the higher the incidence of instrument failure.[97] Gabel *et al*. (1999) found that when rotational speeds in the region of 333 rpm were used, the risk of instrument failure and separation was four times greater than with rotational speeds in the region of 167 rpm.[96] In this particular study, extracted molar teeth were used as subjects. Significantly, it was also proven that the time it took before endodontic instruments separate dramatically reduced as soon as the rotational speed increased.[98]

Although these and other studies have indeed proven that the failure rate increases with an increase in the rotational speed, certain endodontic instruments are specifically designed to be used with higher rotational speeds. The manufacturers advocate that instruments like the TwistedFile (SybronEndo) should be used at speeds ranging from 500 to 625 rpm's. It is claimed that this file is 70 % more flexible and two to three times more resistant to cyclic fatigue than other instruments.[43]

Instrument size and radius of curvature

Pruett *et al*. (1997), in ground-breaking work, proved that factors including radius of the root canal curvature, angle of the root canal curvature and diameter of the endodontic instruments were more important as predictors of instrument failure and fracture than the speed at which the nickel-titanium rotary instrument operates.[56] The engine-driven ProFile (Dentsply/Maillefer) rotary endodontic system was used in this study and Endodontic Training Blocks (Dentsply/Maillefer) were used to keep all parameters (curve angle, curve radius and instrument sequence) the same.

Published findings show that increased curvature of a root canal and an increase in the diameter of the master endodontic instrument to reach the full working length of the measured root canal, lead to a higher tendency to canal transportation, canal straightening and aberration of the original anatomy.[99]

Reports also show that as soon as the angle of curvature of the root canal increases, the incidence of endodontic instrument failure escalates.[100] Considering all the variables of root canal anatomy, the most influential in endodontic instrument failure is the radius of the root canal curvature.[101]

Access cavity preparation

Undeniable advantages stem from adequate access preparation in avoiding complications in the cleaning and shaping sequence. The access preparation should have: no obstructions of the root canal orifices either by dentine or restorative material; and clear, visual direction to enable instruments to approach the apical portion of the root canal or at least the point of first curvature.[102] These initial steps may take some time, but an endodontic instrument that can negotiate a root canal with minimal resistance has a reduced risk of failure and separation. The aim is to decrease the torsional and bending stress on the instrument.

Patients with limited mouth opening are a further risk, as the particular tooth/teeth to be treated cannot be easily reached and the design of the access-cavity preparation becomes even more crucial.[103]

Canal orifice enlargement

The main purpose of canal orifice enlargement/pre-flaring is to aid the negotiation and manipulation of instruments to the apical parts of the root canal. The proper enlargement of the orifices of root canals becomes more valuable when molar or multi-rooted teeth or teeth with severe curvatures are being treated.[104,105]

The burs used to effectively enlarge the orifices are: number 2 or 4 long-shank, slow-speed round burs or numbers 3 and 4 Gates Glidden burs.[104,105] Correct use will achieve the necessary amount of enlargement to allow the rotary nickel-titanium instruments to enter with the least amount of torsional and bending stress coronally. The ideal coronal enlargement needs to be oval shaped and approximately 2mm to 4mm deep.[18]

Surface condition and inspection of instruments

The manufacturers of rotary nickel-titanium instruments advocate that the instruments be inspected constantly for defects and micro-cracks that can lead to instrument fracture. On rare occasions the rotary nickel-titanium endodontic instrument can fracture without any prior warning even if a thorough inspection was performed before use.[97]

Nickel-titanium endodontic instruments have a drawback in comparison with stainless steel instruments, as in the latter it is easier to detect deformation and metal fatigue, which alert the operator to the potential danger of instrument fracture.[69] It would seem that inspection of nickel-titanium rotary endodontic instruments by means of visual inspection only is insufficient to detect deformation and potential instrument failure.[97] More precise methods are indicated.

Effect of sterilisation on the instrument

Yared (2008) brought to the attention of endodontists two important factors: there is always the risk of fracture of the instrument caused by fatigue through repeated use; and the Spongiform Encephalopathy Advisory Committee 2006 found that a risk of cross-contamination exists because it is not possible to completely clean and sterilise the endodontic instruments after use.[75,106]

The Prion Protein (PrP) can be described as a developmentally regulated glycoprotein found in mammals. When the native prion protein (PrPC) is transformed to an alternative conformation (PrPSc), it is believed to play a vital role in the pathogenesis of disorders – namely "transmissible spongiform encephalopathies" (TSEs/"prion diseases").[107] A recent study reported that prions were found in human pulp tissue.[108]

Tooth structure and organic debris adhere to the surface of nickel-titanium endodontic instruments, even though the instruments are thoroughly decontaminated and ultrasonically cleaned.[71,109,110] This raises the question: What is the effect of such stringent sterilisation procedures on endodontic instruments? Endodontic circles accept the fact that thermo-cycling causes metal fatigue to some extent, but researchers are unable to decide which specific type of thermo-cyclic procedure causes the most damage. Some studies have even concluded that thermo-cyclic sterilisation does not affect endodontic instruments or that any adverse effects are of no clinical significance.[111,112,113]

The introduction of a single-use nickel-titanium endodontic instrument to reduce the risk of both instrument failure and cross-contamination would therefore make sense.

Irrigation and lubrication

Mechanical cleaning and shaping of the root canal system and irrigation cannot be separated from the debridement sequence which is designed to remove infected tissue from the root canal. Scanning Electron Microscopic (SEM) studies conducted by various authors have proven that if irrigation (and some sort of lubrication) is not used during cleaning and shaping, debris will pack in the root canal, especially in the apical portion, and form "dentinal mud".[114,115,116]

The main purpose of irrigation and lubrication is to ease instrument negotiation in the root canal system – especially in narrow, constricted areas – and to reduce torsional stress on the instrument; in this way lowering the risk of instrument failure.[18] One study showed that these adjunctive procedures reduced the torsional stress on the instrument by as much as 400%. A comparison was made between preparing a root canal system without any form of lubrication or irrigation and preparing the root canal system with a variety of irrigants (water, RC-Prep, sodium hypochlorite and ethylenediaminetetra-acetic acid (EDTA).[117] The Quantec rotary nickel-titanium system (NT Company, Chattanooga, Tennessee) was the instrument of choice in this particular study. RC-Prep reduced the torsional stress the most on the instrument at depths of 10mm and 12mm, followed by water, EDTA and sodium hypochlorite. However, at a depth of 8mm into the root canal system, EDTA effected more reduction of torsional stress than any other lubricant or irrigation solution tested. Cleaning and shaping the root canal system without any form of lubrication or irrigation showed the highest levels of torsional stress on the endodontic rotary instrument in this study.[117]

A very recent study demonstrated that when endodontic instruments were immersed in sodium hypochlorite solution of a concentration of 5.25%, the instrument had markedly less resistance to fracture when exposed to cyclic fatigue.[118] This finding is most relevant when one considers that sodium hypochlorite is the most common and trusted irrigation solution in endodontics and is used by most clinicians.

Rotary instrument manipulation

The manner in which the rotary nickel-titanium instrument is handled is arguably one of the most important factors contributing to instrument failure. Dederich and Zakariasen (1986) advocate that instruments used in a smooth, cyclic and axial motion (up-and-down motion without allowing the instrument to rotate in one area for a longer period) will reduce the risk of instrument failure.[119] More recent studies have confirmed these recommendations.[4,61,98]

Instrument design

Three design factors that influence the failure rate of nickel-titanium instruments stand out. These are instrument size, instrument taper and cutting flute depths.[80,120,121,122,123]

The size of the instrument will determine how many times it should be used within the root canal before it should be replaced.[124] Chaves Craveiro de Melo *et al.* (2002) concluded that larger instruments are more likely to fracture in the cleaning and shaping sequence.[120]

The taper of the instrument can also play a role in the frequency of instrument separation. Nickel-titanium instruments with a taper of 0.04 had more resistance to fracture than 0.06 instruments.[123]

The cutting flute depths are the final factor influencing failure rate of nickel-titanium instruments. The combination of deep-cutting flute depths and progressively increasing and variable tapers provides great risk of instrument failure. Different cross-sectional diameters along the complete length of the instrument shaft will pose higher levels of torsional stress when engaged on the root canal walls during the cleaning and shaping procedure. The shallower the cutting flutes and more even the taper and cross-sectional diameter of the instrument, the more evenly the forces (torsional and bending stresses) are distributed along the instrument shaft, which makes the instrument more resistant to instrument failure and separation.[125,123,126]

Rotation vs reciprocation

Different systems that make use of alternating movements have been studied in order to find a way to decrease the risk of instrument fracture.[75,127,128] The reciprocating motion would, in theory, reduce the number of cycles of the instrument and, therefore, reduce the cyclic fatigue on the instrument compared with rotary instruments used in a consistent rotating motion.[129,130] Varela-Patiño *et al*. (2008) tested the assumption by using Endodontic Training Blocks.[128] Their study confirmed that when operated in a reciprocating motion the nickel-titanium endodontic instruments were less prone to separation.

During repeated rotation, with continuous compression and flexion, micro fractures form within the nickel-titanium file that will lead to instrument fracture.[97] The alternating rotary movement decreases the binding of the file to the root canal wall, reducing torsional stress in this way and is recommended not only to reduce risk of instrument fracture, but also to decrease the chances of root canal deformation and to improve the centring ability of the instrument.[75,128,131,132,133] Very recent studies were able to confirm that using nickel-titanium instruments in a reciprocating motion will increase the lifespan of the instrument by minimising cyclic fatigue and flexural stress as the number of cycles required within the root canal is lower.[129,134]

Reproducible glide path preparation prior to instrumentation

A factor that could greatly influence the failure rate of nickel-titanium endodontic files is the initial use of stainless steel files in the creation of a 'glide path' before the first rotary instrument is introduced into the root canal.[135,136]

A glide path is a smooth passage that extends from the canal orifice in the pulp chamber to its opening at the apex of the root.[137] This should in theory, provide a continuous, uninterrupted pathway for the rotary nickel-titanium instrument to enter and to move freely to the root canal terminus. The main purpose of a glide path is to create a root canal diameter the same size as, or ideally a size bigger than, same size as, or ideally a size bigger than, the first rotary instrument introduced.[135,136,138]

Varela-Patiño (2005) found that fewer fractures occurred when a wide and smooth-walled glide path was created and the canal was pre-flared before the introduction of rotary files into the root canal.[136] It was speculated in this study that the creation of a smooth glide path by means of stainless-steel hand files meant that most of the anatomical interferences that can cause obstructions to the rotary nickel-titanium files were eliminated.

Various methods have been advocated to create a glide path. Several authors use stainless-steel K-files.[91,139,135,140,141] Mounce (2005) concluded that the use of hand stainless-steel instruments has four advantages: excellent tactile sensation; lower risk of fracture; small K-files being able to mimic the root canal anatomy at the smaller areas of the canal, giving the clinician a better sense of the detailed anatomy of the root canal; and an enhanced ability to negotiate blockages and calcifications.[141]

The small stainless-steel instrument (K-file) should be used in a clockwise and anti-clockwise rotation (watch-wind) to scout the narrow part of the canal, followed by a vertical in-and-out movement. The vertical movement should start with 1mm amplitudes and, once the resistance decreases, the amplitudes can be increased.[137]

Other authors advocate the use of a reciprocating hand piece (SybronEndo) (30 degrees clockwise and 30 degrees anti-clockwise movements) in combination with K-files. Using a hand piece to create the glide path gives the operator the advantage of reducing hand fatigue and cuts down chair time considerably, especially in multiple narrow root canal preparation.[142,143,144]

The most recent development in glide path preparation is the PathFile system (Dentsply/Maillefer). Berutti *et al*. (2009) found that this technology caused less canal aberration and less modification of the original canal anatomy in simulated root canals.[138] The PathFile sequence consists of three files (with a choice of 21mm-, 25mm- and 31mm file lengths) – namely a number 13 (purple with ISO tip size 13, 0.02% taper), number 16 (white with ISO tip size 16, 0.02% taper) and number 19 (yellow with ISO tip size 19, 0.02% taper). Initial preparation of a glide path should be done up to a size 10 K-file before the first PathFile instrument is introduced into the canal.[145]

CONCLUSIONS

The development of endodontic instruments has reached new levels in the last few years. Unfortunately, instrument fracture still remains a major concern for all clinicians performing endodontic treatment. Dental companies have developed different endodontic systems in an attempt to avoid instrument fatigue and failure. The introduction of nickel-titanium as an alloy has changed the world of endodontics forever. In the modern era, the conventional nickel-titanium alloy has been manipulated by various processes to produce endodontic instruments that are much more resistant to torsional and flexural stresses than before. This has led to extreme changes in both the design of instruments regarding shape and size and the procedures needed for optimal results.

The fact remains that clinicians need to respect the limitations of each instrument and to carefully follow the manufacturer's instructions for the cleaning and shaping sequence. Clinical assessment studies and published research show that when operators take the necessary precautions and follow the prescribed instructions regarding the use of the particular endodontic system, the risk of instrument fracture can be as low as four cases per 1000.[146,147]

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