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ABSTRACT

Preparation of root canal system is one of the most important procedures in endodontic treatment. There has been a constant quest for quicker, safer and more efficient method for cleaning and shaping of root canals. Use of automated Ni-Ti instruments was a logical development to improve the efficiency of the treatment. Separation of instruments while preparing root canals is something that has plagued all practitioners. Therefore, an evaluation of effect of speed and torque on the rotary Ni-Ti instruments is of value to the clinician.

The purpose of this paper is to discuss the behavioural properties of Ni-Ti, importance of speed and torque and the necessity for its understanding for effective, safe and successful treatment.

Key words – Ni-Ti instruments, speed and torque, endodontic instruments,

Introduction

The technical demands and level of precision required for successful performance of endodontic procedures have traditionally been achieved by careful manipulation of hand instruments within the root canal space and by strict adherence to the biologic and surgical principles, essential for disinfection and healing. To improve the speed and efficiency of the treatment, recently there has been a resurgence of mechanized or automated system for both preparation and sealing of root canal system.

The purpose of this paper is to discuss the behavioural properties of Ni-Ti rotary instruments, importance of speed and torque and the necessity for its understanding during endodontic preparation for effective, safe and successful treatment outcome.

Clinical evidence demonstrate that root canal systems can be cleaned and shaped and obturated in three dimensions with a high degree of predictability approaching 100% success. Three major elements determine the predictability of successful endodontics. The first is the knowledge, the second is the skill and the third is the desire. Almost 30 years ago, Schilder introduced the concept “cleaning and shaping” of root canals. In fact, most of the obturation the problems are really problems of cleaning and shaping. The secret to successful endodontics is proper shaping.

What is the modern meaning of cleaning and shaping? Cleaning refers to removal of all contents of the root canal system before and during shaping. Shaping refers to a specific cavity form with five design objectives:

1. Develop a continuously tapering conical form in the root canal preparation.
2. Make the canal narrower apically, with the narrowest cross-sectional diameter at its terminus.
3. Make the preparation in multiple planes.
4. Never transport the foramen.
5. Keep the apical foramen as small as practical.

**Ni-Ti in Endodontics**

The shaping of curved canals presents a considerable problem for practitioners when stainless steel instruments are used. There is a tendency for all preparation techniques to transport the prepared canal from its original axis.

Deviation from the original curvature can lead to procedural errors, such as ledge formation, zipping, stripping and perforations. As a consequence, new endodontic instruments and techniques have been introduced which help to minimize these risks.

Parameters including radius of curvature, angle of curvature, instrument size and the point of maximal instrument flexure were all found to have a significant effect on the number of cycles to failure and location of breakage.

**Radius of curvature and angle of curvature**

\[
\begin{align*}
a1 &= 60^\circ \\
r1 &= 5\text{mm} \\
a2 &= 60^\circ \\
r2 &= 2\text{mm}
\end{align*}
\]

Fig 1 describes canal geometry using two parameters. Radius of curvature \(r\) and the angle of curvature are determined on the same tooth. This teeth accurately depict the 60 degree angle \(a1=a2\).\(^2\)

Angle of curvature \(a\) is determined by the angle formed by the lines that intersect at the circle’s center. These two lines are perpendicular to the lines drawn along the long axes of the coronal and apical portions of the root canal space. Points \(c\) and \(d\) are the points where in the canal deviates from the straight lines and begin or end the curved portion of the root canal space. The angle \(a\) is taken to be the angle formed by the arc in degrees between points \(c\) and \(d\). The arc lies on a circle whose size is specified by its radius, and the circle’s radius is taken to be the radius of curvature of the canal in that local area. The circle’s radius is the radius \(r1\) and \(r2\) of the curved portion of the root canal space and defines how abruptly the canal curves. The canal geometry of these two teeth differs only in the radius of curvature \(r1\) and \(r2\), whereas the angle of curvature \(a1\) and \(a2\) equals 60 degrees. A represents a sweeping canal curvature having a 5 mm radius of curvature \(r1\). B represents an abrupt canal curvature having a 2 mm radius of curvature \(r2\).

Clinically, the radius of curvature and angle of curvature of any root canal space could be measured using this technique with the aid of a circle gauge.\(^2\)

Of the two canal shape parameters, angle and radius of curvature, radius of curvature was the most significant factor of canal shape affecting the number of cycles to failure of Ni-Ti engine driven rotary instruments. As the radius of curvature decreases, instrument stress and strain increases, and the fatigue life decreases, which may contribute to instrument breakage and canal transportation in clinical situations.\(^2\)

More flexible Ni-Ti instruments have been developed and found to be efficient. The super
elasticiy of Ni-Ti alloy allows these instruments to flex far more than stainless steel instruments before exceeding their elastic limit, allowing easier instrumentation of curved canals while minimizing canal transportation. With the development of Ni-Ti alloy which offers a tough, modulling, corrosion resistant instrument with mechanical memory, these instruments gained significant popularity and are routinely included in current endodontic armamentarium. The automated use of Ni-Ti endodontic files was a logical development to increase the efficiency of clinical treatment.

Metallurgy of Ni-Ti

After years of relative inactivity with regard to improvements in metals and alloys used to make endodontic instruments, we now have instruments made from Nickel-Titanium (Ni-Ti) which is a remarkable alloy. The instruments made of Ni-Ti offer possibilities for improving the speed and efficiency of treatment, as well as achieving greater precision and accuracy. This alloy exhibits super elastic behaviour, allowing it to return to its original shape upon unloading following substantial deformation. By contrast, other metals such as stainless steel sustain plastic deformation leading to permanent shape change when deformed similarly. The super elastic property of Ni-Ti has been known for 30 years, and was discovered by chance by Buchler and Wang while searching for nonmagnetic, salt-resisting, water proof alloys for naval use. Alloys that show super elasticity undergo a stress-induced martensitic transformation from a parent structure which is austenite. Upon release of the stress, the structure reverts back to austenite, recovering its original shape in the process. Deformations involving as much as 10 percent strain can be completely recovered in these metals, as compared to a maximum of one percent in conventional alloys.¹

Nickel-Titanium also known as “Nitinol” (Ni-Ti Naval Ordinance Laboratory) in the United States, has been manufactured in Shanghai, China since 1979 as “Nitalloy”—56% of Nickel and 44% titanium. The first investigation of nickel titanium in endodontics was reported in 1988 by Walia, Brantley, and Gerstein.

Shape memory alloys, such as Ni-Ti, undergo a phase transformation in their crystal structure when cooled from the stronger, high temperature form (austenite) to the weaker, low temperature form (martensite). This inherent phase transformation is the basis for the unique properties of these alloys, in particular shape memory effect and super elasticity.

This latter property is important for endodontic use. Ni-Ti alloys can show a superelastic behaviour if deformed at a temperature which is slightly above their transformation temperatures. This effect is caused by the stress-induced formation of some martensite above its normal temperature. Because it has been formed above its normal temperature, the martensite reverts to undeformed austenite as soon as the stress is removed. This process elicits a springy, rubber like elasticity from the alloy. The typical loading and unloading behaviour of super elastic Ni-Ti (stress-strain curve) when subjected to tensile stress is shown in the Fig 2. The super elastic behaviour is typically represented by the martensitic yield plateau within which the stress remains approximately constant until the martensite finish (Mf)
transformation stress, a value which is slightly lower than the elastic limit, is reached.

This plateau is clinically useful, because it allows easy and efficient instrument deformation without significantly increasing the applied load. This explains why Ni-Ti instruments require a certain amount of torque and rotation to overcome the linear elastic response of the initial structure and reach the martensite start clinical stress (Ms). The figure also explains why Ni-Ti rotary instruments should be operated with constant speed and torque (constant load) when the martensite start clinical stress is reached, to maximize efficiency and minimize iatrogenic errors. Andreasen and Morrow have demonstrated that stainless steel wires undergo a much larger change in force compared to the change in force of Ni-Ti wires when deflected an equivalent amount (spring rate).

Clinically, this means that Ni-Ti is more flexible, requires less force to undergo a change in deflection (i.e., when negotiating a curved canal) and consequently requires low recovery loads, thus reducing the tendency of straightening the root canals.

Martensite is the more deformable, lower temperature phase present in Ni-Ti, which is able to absorb up to 8% recoverable strain. Upon minimal further deformation there is a small linear elastic response up to the elastic limit (E), caused by the elastic deformation of the self-accommodated martensitic product, in which a small amount of slip and dislocation motion is apparent. Further deformation results in plastic deformation and final failure. In clinical practice, plastic deformation of Ni-Ti rotary instruments should be avoided, because it may easily lead to fracture. As shown in figure 2, the range of deformation allowed by the plastic field is twice as small as that allowed by the elastic field.

Extensive tension testing of Ni-Ti wires has been done in the last few decades. Researchers have found that compression, torsion and flexural loading of Ni-Ti wires result in similar constitutive behaviour to that observed in tension. However, the critical stress in torsion is much smaller than the stress observed in tension or compression, while the recovery strains are much greater.

Importance of Speed and Torque Speed

Speed refers not only to revolutions per minute but also to the surface feet per unit that the tool has with the work to be cut.

In endodontics speed varies from 150—40,000 rpm. Greater the speed, more the cutting efficiency, but at higher speed, there are more disadvantages such as:

1) loss of tactile sensation
2) breakage of instruments preceded by flute distortion
3) change in anatomical curvature of canal
4) loss of control

Torque

Torque (also called a moment) is the term used about forces that act in a rotational manner. Examples of torque or moment application are turning a dial, flipping a light switch, drilling a hole or tightening a screw or bolt.

As shown in the Fig 3 of a ratchet, a torque is created by a vertical force applied at the
end of the handle. The force, \( F \), applied to the ratchet causes a tendency to rotate about point 0, the force can be broken down into two components: a radial component, \( F_{\text{rad}} \), parallel to the ratchet handle that does not contribute to the torque and the distance from point 0 to the point of action \( F \) is described by the direction vector, \( r \). The moment arm, \( l \) is the perpendicular distance between point 0 and the line of action of \( F \).

If we were to shorten the moment arm by applying the force closer to the head of the ratchet, the magnitude of the torque would decrease, even if the force remained the same. Thus, if we change the effective length of the handle, we change the torque.

According to Marzouk, torque is the ability of the handpiece to withstand lateral pressure on the revolving tool without decreasing its cutting efficiency.\(^6\)

Torque is dependent upon the type of bearing used and the amount of energy supplied to the handpiece.

**Importance of Torque- during Cleaning and Shaping**

Torque is another parameter that might influence the incidence of instrument locking, deformation, and separation. Theoretically, an instrument used with a high torque is very active and the incidence of instrument locking and consequently deformation and separation would tend to increase, whereas a low torque would reduce the cutting efficiency of the instrument, and instrument progression in the canal would be difficult. The operator would then tend to force the instrument and may encourage instrument locking, deformation and separation.

A variety of speeds for different rotary instrumentation have been recommended by the manufacturers. Conventional endodontic motors to recent motors use a wide range of speed of 150 rpm - 40,000rpm, which are either controlled by electrical or air-driven instructions handpieces. Depending of the manufacture, and the condition of the handpieces (i.e. old or new), each single handpiece has a different degree of effectiveness, which results in different torque losses, which are very difficult to define. Hence, possibility of calibrating the handpieces is an important issue, which every endodontist must be aware of, while choosing an appropriate handpiece, according to the required speed and torque.

**Role of Handpiece**

A handpiece is a device for holding rotating instrument, transmitting power to them and for positioning them intraorally.

Both speed and torque in a handpiece can be modified by the incorporation of gear systems. Operative procedures involving rotary instruments can be optimized by correct selection of handpieces and corresponding gear ratios. Handpieces can incorporate gearing systems of various types but gearing is limited by the need to maintain the drive concentrically through the handpiece and head.

A common method of gearing a handpiece is the use of an epicyclic ball-race gear system. This is usually located in the shank of the handpiece. The epicyclic ball race can be used to either increase or decrease the speed of rotation from the drive spindle depending upon which way around it is mounted.\(^8\)

The basic design is a modification of a ball-race bearing. If the outer ring of an ordinary bearing is held stationary whilst the inner ring is turned, the cage separating the balls turn at a much reduced speed. The speed reduction is proportional to the relative diameters of the inner and outer rings. In the shank of the handpiece the cage unit is extended and is attached to either the drive shaft or the driven shaft depending on whether a speed reduction or increase is needed.
The great advantage of using a ball race gearing system is that it is very smooth and relatively quiet in operation. Surprisingly high torque can be transmitted without the ball-bearings slipping. Two units can be used serially where larger changes in speed are required.8

Full miniaturized epicyclic gear boxes with toothed gears are now being used in some top range handpieces. Provided that these are manufactured from strong alloys and are designed effectively, they can provide excellent and powerful transmission of torque.

Such boxes are particularly appropriate for speed increasing handpieces. Reduction handpieces reduce the speed of the drive whilst increasing the torque. Electronic control systems can be used to maintain the speed of the motor against the effects of increasing load during cutting.8

Torque control motors allow the setting of torque generated by the motor. In low torque control motors, torque values set on the motor are supposed to be less than the value of torque at deformation and at separation of the rotary instruments. Where as in high torque control motors, the torque values are relatively high compared to the torque at deformation and at separation of the rotary instruments. During root canal preparation all the instruments are subjected to different levels of torque. If the level of the torque is equal or greater than the torque at deformation or at separation, the instrument will either deform or separate. Theoretically, with low torque control motors, the motor will stop rotating and can even reverse the direction of rotation when the instrument is subjected to torque levels equal to the torque values set on the motor. Thus instrument failure could be avoided. With high torque control motors, the instrument torque at deformation and separation would be reached before the relatively high torque set on the motor. Consequently, the instrument would deform and separate.

The main problem with Ni-Ti rotary instrumentation techniques probably is instrument failure. Intracanal instrument fracture is an iatrogenic error which can seriously jeopardize the success of root canal therapy. Preutt et al has shown that the continuous cycle of tensile and compressive forces to which engine driven instruments are subjected, produce a very destructive form of loading. Moreover, mechanical stress on Ni-Ti rotary instruments is proportional with the motor torque. Hence torque control is an important factor, to reduce the risk of Ni-Ti fracture. If there is no torque control, then once load is applied to rotating instrument, it will stop rotating.5

Slow speed, low-torque(right-torque) motors

The high stress is not clinically important in straight canals where the resistance to dentin removal is low. On the contrary, in curved or calcified canals, the resistance is high and the instrument may become blocked near the tip. In these situations, the high torque provided by the motor might immediately lead to fracture of the blocked instrument, especially since the clinician usually has no time to stop or retract the instrument.

The use of slow-speed high torque Ni-Ti rotary instrumentations has lead to many iatrogenic errors. Ideally it should, now be changed to slow-speed low-torque or preferably right-torque motors, since each instrument has a specific ideal (right) torque. The values are usually low for the smaller and less tapered instruments, and high for the bigger and more tapered ones.

To minimize the risk of intracanal breakage the instruments should be operated in a range between the martensite start clinical stress values and the martensite finish clinical stress values, which is a safe and efficient load. However, this range is small and difficult to determine. With good approximation, it can be defined to be slightly lower than the limit of
elasticity. The elastic and fracture limits of Ni-Ti rotary instruments are obviously dependent on design, dimensions and taper. This means that the right torque value for each individual instrument must be calculated by the manufacturers to obtain optimum cutting performance while minimizing risks of failure. Moreover, motors must have a very precise, fine-adjusted control of torque values, in order to take advantage of these concepts of not exceeding the limit of elasticity and consequently avoiding plastic deformation and intracanal breakage.

Conventional endodontic motors are not able to allow precise, low-torque settings for different reasons. A step-motor with computer-controlled electronics, which allows fine adjustment of the torque values for each and every instrument of different brands, is presently available as prototype (Endostepper, SET, Emmering, etc.). The maximum torque values for the individual instruments can be adjusted and programmed such that the elastic limit is not exceeded. All data for each instrument (including operating speed, limit of elasticity, maximum torque and angle of right-left motion) are stored in the computer memory. If the motor is loaded right up to the instrument-specific limit-torque, the motor stops momentarily and attempts to start again. If the externally required torque (determined by anatomic complexities and hardness of dentin) is so high that the motor cannot start automatically, by means of a pedal function, the motor executes a precisely defined left-right motion, which succeeds in safely freeing the blocked instrument. Once the instrument is released, the motor rotates in the usual, programmed direction.

This safety mechanism was developed to reduce the risk of instrument fracture. The main advantage of this motor was that it dramatically increased tactile and mental awareness of rotary instrumentation. This was a fundamental step in reducing the risk of instrument fracture to a minimum.5

The latest development with regard to torque control is the incorporation of gear systems within the handpiece that regulates torque depending on the size of the rotary instrument. (Endoflash-Kavo, Anthogy Ni-Ti control-Dentsply). This obviates the need for torque control motors.

Future developments in Ni-Ti files

Several areas offer exciting research possibilities to further enhance the performance of Ni-Ti files. These research possibilities include:

- Use of ion implantation and thermal nitridation to provide harder and wear resistant cutting edges in the file.9
- Investigation of failure models in Ni-Ti files to develop mathematical models to accurately predict the life expectancy of these files during use.
- Optimization of flexibility, bending and torsional strength of files without sacrificing cutting ability, by using modern mechanics and analysis methods: for example, finite element analysis.

Conclusion

This article is aimed at providing a comprehensive review of rotary endodontics with emphasis on the behavioural properties of Ni-Ti and its mode of application. Furthermore, the use of right speed and torque are stressed for controlled instrumentation.

Finally, the authors feel that it would be unwise to attempt Ni-Ti rotary endodontics without complete understanding of physical and mechanical properties of Ni-Ti Instruments.

References


