THE ROLE OF TORQUE IN ROOT CANAL INSTRUMENTATION
RUNNING HEAD: TORQUE IN ROOT CANAL SHAPING

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ABSTRACT

Root canal instrumentation is essential for the success of endodontic treatment. Among the various factors that influence the effectiveness of instrumentation, torque is particularly important. Adjusting the torque during root canal instrumentation not only improves dentin cutting efficiency but also decreases the potential for instrument fracture, canal transportation, or perforation. This paper explores the role of torque in endodontics, including its definition, measuring methods, effects on instrumentation, and implications for clinical outcomes. It specifically examines the parameters that influence torque generation during root canal instrumentation.

Keywords: root canal instrumentation, torque, instrument fracture

Introduction

From the moment they appeared on the market in the 1990s until today, NiTi rotary instruments have taken endodontics to the next level. Compared to hand instruments made of stainless steel, NiTi instruments have superior flexibility, which enables the treatment of root canals with complex morphology. In addition, they have a better ability to canter the root canal decreasing the risk of procedural errors. NiTi files reduce root canal treatment time, which benefits both dentists and patients [1].

Despite the aforementioned advantages as well as advances in design and manufacturing processes, fracture of NiTi endodontic instruments is still a relatively common problem in daily practice, especially when treating calcified and curved root canals. This problem can compromise both the outcome of the root canal treatment and the patient's confidence. NiTi instrument fracture can be a result of material fatigue, i.e., repeated compressive and tensile stresses along the working part of the instrument. Fracture can also occur as a result of torsional stress that occurs when one part of the instrument (most often the apical part) gets stuck and the other part continues to rotate [2].

The use of rotary instruments may also lead to phenomena that increase the risk of the instrument fracture. The first phenomenon is taper lock, which occurs due to the extensive contact surface between the instrument and the root canal wall, instantly increasing torsional stress [3]. The second phenomenon is the screw-in effect, which refers to the tendency of the rotating instrument to retract apically, detectable through tactile sensation. The screw-in effect can cause instrument jamming and fracture due to torsional stress. Files with active tips, common in root canal retreatment, are more likely to experience this effect [4].

Most clinical work in dentistry is based on the action of rotating force on instruments. Torque and speed are the basic characteristics of rotational motion. The effectiveness and safety of instrument use depend on the adaptation of these characteristics to the conditions within the root canal. Therefore, the aim of this paper is to explain the meaning of these terms and the implications they have for root canal instrumentation. In particular, factors that influence torque generation during endodontic treatment will be explained.

Operative torque

Mathematically speaking, torque is the product of force and its distance from the axis of rotation. The unit for torque is Nm, and since small distances are used in endodontics, the common unit is Ncm. In terms of mechanics, torque is the amount of force required to rotate an object around its longitudinal axis. Applied in endodontics, torque is the force required to rotate NiTi instruments [5].

However, what interests every dentist performing root canal treatment is the operative torque. Operative torque is a measure of the force required for an instrument to progress through the root canal, cut dentin, remove debris, and reach a specified working length without fracturing it. Therefore, it is a balance between the efficiency of the instrument on the one hand and the safety of its application on the other. Operative torque is a dynamic quantity, meaning that it changes at different stages of root canal treatment. This value depends on a number of factors, including root canal anatomy, dentin hardness, instrumentation technique, root canal instruments characteristics, operator experience, and torque and speed settings on the endomotor itself [6].

Influence of root canal anatomy on operative torque values

A large number of studies have found that the shape of the root canal affects the fatigue and lifespan of endodontic instruments [7,8,9]. There are differences in the number, length, diameter, and curvature of root canals between different groups of teeth. During the instrumentation of smaller diameter canals, a greater operative torque is generated compared to larger diameter canals. Additionally, the radius of curvature has a greater influence on the operative torque generation than the angle of curvature during instrumentation of curved root canals. The shorter the radius of curvature, the greater the torque generated. It has been found that changing the radius of curvature from 15 mm to 5 mm reduces the lifespan of the instrument by a factor close to 10 [10].

Higher operative torque values were recorded during instrumentation the apical third of the root canal. In some cases, the operative torque values are higher when shaping the coronal compared to the middle third of the root canal, which is explained by the presence of calcifications at the entrances to the root canals [11].

Influence of instrument characteristics on operative torque values

The quality of mechanical root canal preparation is directly influenced by the design of endodontic instruments. There are numerous factors that affect the efficiency of endodontic files [12].

Over the past years, the cross-sectional design of endodontic instruments has changed. The main tendency has been to reduce the contact area between the instrument and the root canal wall. It has been found that instruments with a rectangular cross-section generate almost twice as much torque as triangular ones. This is explained by the fact that instruments with a triangular cross-section are more flexible and therefore have a longer lifespan [13,14].

Some modern endodontic instruments have a variable cross-section along their working part [15]. Additionally, modern endodontic files might have an eccentric axis of rotation, in contrast to the centric axis of rotation of traditional NiTi files. This reduces the contact area of the file with the root canal wall and thus the flexural and torsional fatigue. Furthermore, instruments with an eccentric axis of rotation facilitate the removal of debris during root canal preparation [16].

The taper of endodontic instruments can be constant or variable. In a constant taper instrument, the increase in diameter per unit length is constant. Instruments with variable taper can be progressive or regressive, depending on whether the diameter of the instrument increases or decreases from the tip to the handle. Endodontic files with constant taper are suitable for straight canals and canals with minimal curvature. Even though there are very conservative dentin removal files available on the market with constant taper 0.04 or less, using the file with greater conicity could result in a larger amount of dentin being removed. Variable taper endodontic files are more flexible and suitable for curved, i.e., anatomically more complex canals although this also depends on other properties of the cutting part of the instrument and alloy. When working with these endodontic files, there is less chance of taper lock and screw-in phenomena [17].

The modification of the cutting edges of the instrument could also contributed to the generation of lower operative torque values. A lower screw-in effect, and thus the generated torque, was observed when using a radially landed cutting edge compared to sharp cutting edge [18,19]. In addition, the use of a radially landed cutting edge allows the instrument to remain centrally positioned in the root canal [20,21].

The distance between the cutting edges determines the pitch of the instrument. Instruments with a small pitch generate a higher torque because dentin accumulates faster within the grooves, reducing cutting efficiency, which can result in the application of a higher apical force [17]. A large number of modern endodontic instruments have a variable pitch along the active part [22].

The angle that the cutting edge of the instrument makes with its longitudinal axis is called the helicoid angle. Instruments with a higher helicoid angle generate a lower torque and thus lower torsional stress on the instruments [23].

NiTi alloy can exist in two crystal structures called austenitic and martensitic phases, which depend on stress and temperature [24]. Conventional NiTi instruments are in the austenitic phase at room temperature. When external stress is applied, such as torsional stress or friction of the instrument against the root canal walls, transformation to martensite occurs [1].

The martensitic phase helps reduce the risk of endodontic instrument fracture under high stress conditions because it can deform rather than break. Since the martensitic state induced by stress is not stable at room temperature, once the stress is removed, the deformed NiTi alloy immediately returns to the austenitic phase. This transformation is responsible for the super-elastic properties of conventional NiTi instruments, i.e., their ability to return to their original shape after deformation, which is called the spring-back or shape memory effect [25].

Improved properties of endodontic instruments are achieved through heat treatment, surface modifications and slight changes of the ratio between alloy components. Heat treatment aims to influence the transition temperatures of the NiTi alloy and modify the fatigue resistance. The heat treatment process reduces the internal stress of the NiTi alloy and increases the phase transformation temperature of NiTi, resulting in a more martensitic phase at clinically relevant temperatures. Heat-treated NiTi instruments have greater flexibility and fatigue resistance than conventional NiTi instruments. The whole point of heat treatment is to make the martensitic phase stable under clinical conditions [25,26].

Microcracks are often formed on the surface of the instrument, which indicate the first stage of the fatigue phenomenon. Therefore, a treatment that improves surface smoothness is expected to prevent cracking and increase fatigue resistance.

Electropolishing refers to any electrochemical process aimed at reducing material surface irregularities and achieve high gloss. It is performed by immersing the instrument in a specially formulated, usually acidic, electrolyte solution and passing direct current through it to facilitate the selective dissolution of the material. However, there is conflicting evidence about the benefits of this surface treatment [27].

To create a protective oxide coating on their surface, most NiTi endodontic files, such as ProTaper Gold and Reciproc Blue, use a patented heat treatment method that frequently involves air or a controlled atmosphere. In some cases, the surface hardness and wear resistance of heat-treated NiTi instruments have been improved by surface engineering techniques. This involves physical vapor deposition in a vacuum, where the instruments are covered with a thin film or coating. Several manufacturers have therefore devised thermomechanical processing methods to create a titanium oxide surface layer on NiTi instruments. Differences in the thickness of the titanium oxide layer result in different colours of the instrument. However, some heat treatment processes do not necessarily result in the formation of a titanium oxide layer that will cause instrument colour change, such as M-wire [28-30].

Characteristics and indications for the use of austenitic and martensitic instruments

Instruments in the austenite phase have the shape memory effect described above. These instruments have increased resistance to torsional fatigue and fracture at higher torque values. They cut dentin more efficiently and advance through the root canal faster, but have less flexibility than instruments in the martensitic phase. Due to the mentioned characteristics, instruments in the austenite phase are used for the treatment of straight and slightly curved root canals [31]. In addition, the use of an austenitic alloy in pathfinding files can potentially compensate for the decreased torque resistance caused by their smaller diameter. Retreatment procedures are also shorter when performed with austenitic instruments compared to martensitic ones [32].

Instruments in the martensitic phase can be bent at room temperature and retain their shape, which is called the control memory effect. They have increased resistance to cyclic fatigue, but fracture at lower torque values. Therefore, instruments in the martensitic phase are used when shaping strongly curved root canals, when bypassing ledge and in situations of difficult access, e.g., when the patient cannot open his mouth sufficiently. They cut dentin less effective and advance more slowly towards the apical part, but they have greater flexibility [33].

The irrigation protocol recommends heating the NaOCL to increase its animicrobial and organolytic activity. However, increasing the temperature of the irrigant affects the properties of the heat-treated endodontic files. As the temperature rises, the instrument becomes stiffer because the temperatures of its phase transformations change [34,35]. It has been proven that 33% more force is required to bend the last five millimeters of the instrument with irrigant heated to 46°C than with irrigant at 37°C. To reconcile the improved properties of heated irrigate and the super elastic properties of NiTi instruments, it is recommended to use room temperature irrigant during root canal treatment, and to use heated NaOCl as a final irrigant after root canal instrumentation [36].

The influence of operator- dependent factors on operative torque values

The generation of operative torque is influenced by factors that depend on the operator himself such as: creation of a glide path, depth and number of insertions, movement during instrumentation, choice of system kinetics, lubrication and experience of the therapist [37].

Creating a glide path before root canal instrumentation has been proven to reduce operative torque values on subsequent instruments. This implies the importance of creating a glide path during root canal treatment [38].

When treating a root canal, it is necessary to cover a shorter vertical path (pecking motion), i.e., make inward-outward movements with an amplitude of 1 to 3 mm (shorter in curved and narrowed canals). This movement counteracts the twisting forces that occur during rotation. Progressive canal enlargement through repeated, controlled insertion may lower torque during subsequent passes, provided that debris is effectively removed and the file is not binding [39-41]. Usually, three vertical movements and cleaning of the file grooves are performed in each cycle. Removal of debris significantly contributes to reducing the operative torque. Brushing movements generate lower torque than pecking movements [42].

During a dental procedure, the dentist adopts different hand positions, looking appropriate support for work. By analysing the torque generated by moving the hand in all three spatial planes, it was found that the strongest forces were generated apically, rightward and posteriorly [43]. Every dentist should take care that the hand controlling the endomotor does not generate additional operative torque.

The choice of NiTi file system with a specific kinetics also affects the generation of torque. In systems with reciprocal rotation, clockwise and counterclockwise motion alternate at a certain angle. When the direction of rotation changes from clockwise to counterclockwise, a higer torque is generated. Therefore, the amplitude of the generated torque in continuous motion is lower than in reciprocal motion [44]. The recently introduced adaptive motion implies both continuous and reciprocal rotation, which depend on the torque values. Optimum Torque Reverse (OTR) is a function on the endomotor that enables automatic torque measurement, whereby the measured value controls the direction of rotation. If the load is less than the torque value set on the endomotor, the instrument continuously rotates clockwise. As soon as the torque exceeds a setpoint value, the rotation reverses to an alternating 90° counterclockwise and 180° clockwise until the torque falls below the setpoint. OTR is a more refined version of auto-reverse, but uses a smaller angular rotation for safe feedback about the file's stress. This adaptive motion produces lower torque than continuous rotation [45,46].

The use of lubricants reduces the generated torque, with aqueous solutions have a greater advantage in comparison with gel-type formulations [47,48].

Clinical instrument use varies for each clinician and may result in different blade engagement and torsional stresses during intracanal instrumentation. The torque generated during the work of inexperienced practitioners is greater than that of those with many years of experience [49]. However, it is interesting that in relation to apical force, inexperienced operators produce less apical force than experienced ones [50]. No matter how familiar a dentist becomes with their system, it is still essential not to apply force with a rotating instrument. In addition, pecking at higher speed rotation generates higher vertical forces and torque then pecking at low-speed rotation [51].

Inherent torque and measurement techniques

Each endodontic file has its own specific torque (inherent torque) which is stated in the instruction manual. Inherent torque is, in principle, the maximum force that a file can withstand without breaking. This practically means that endodontic file manufacturers must suggest the right torque values or each individual file to achieve optimal cutting performance while reducing the risk of fracture. Unfortunately, it is not easy to find such a good balance. To optimize clinical use, a rotary NiTi instrument should require low operative torque values and exhibit a high fracture-inducing torque value or exhibit a wider "torque range" between these two values [52].

To assess the torsional resistance of NiTi files, a rotational force is applied until the instrument fractures. The in vitro torsion resistance test according to International Organization for Standardization (ISO) 3630-1 involves immobilization of the 3 mm tip of the instrument, with continuous rotation of the shaft until fracture at a speed of 2 rpm [53]. This method was developed in the 19th century to test the torsional resistance of stainless steel hand instruments, but it is not adapted for testing NiTi rotary instruments, which in clinical practice rotate at much higher speeds than 2 rpm. Currently, there are no international guidlines or standards for assessing the fracture resistance of endodontic rotary instruments [25]. Another problem is that the predefined torque values are based on the mechanical properties of new instruments. Unfortunately, the repeated use of NiTi rotary instruments dramatically affects their fatigue resistance. This concept has been clearly demonstrated in many studies [54-56].

To bring the testing conditions closer to real clinical situations, several in vitro methods have been developed to measure the stress during root canal instrumentation. Root canal shaping can weaken the canal wall due to the removal of dentin and the stress generation. Therefore, methods have been developed that involve counting microcracks before and after root canal instrumentation. Microcrack assessment was performed using stereomicroscopes [57] and micro CT analyses [58,59].

Applying a strain gauge to the root surface has allowed real-time stress measurement during canal instrumentation. However, the stress on the root surface is not identical to the stress on the root canal walls [60].

Several studies have measured stresses using the finite element method, which allows for analysis of stress distribution and concentration depending on material properties and loading conditions [61]. Stress levels during shaping vary depending on the instrument design. The mechanical response of the instruments is influenced by their cross-sectional design, volume, and elasticity, as well as the elastic modulus of the root canal dentine [62-64].

Recently developed torque sensors and improved software have enabled the creation of devices capable of assessing and recording torque in real time during root canal shaping. The operative torque generated by the instrument is measured every 0.1 s and the average torque value can be calculated. The device accurately records a multitude of torsional stresses along the entire working part of the instrument. In this way, the instrument is dynamically evaluated because the torque is measured at all stages of instrumentation from orrifice to apical constriction [42,65,66].

The relationship between speed and torque

The speed represents the number of rotations of the endodontic instrument in one minute and is the driving force for creating torque. If the speed is low, it cannot generate the torque needed to cut the dentin. High speed will create excessive torque, disable the autoreverse function and lead to instrument fracture [67,68]. Speed constancy is of utmost importance to enable the NiTi instrument to be used in a consistent manner during instrumentation. When using an endomotor, the instrument rotates in the canal at a constant speed regardless of root canal conditions and this is possible by adjusting the torque [5]. Unlike speed, torque is influenced by the conditions of the root canal itself, but also by the force applied by the operator, which can be multidirectional [14].

Speed and torque settings are not the same for all clinical situations [40, 44, 69]. Although it is generally necessary to respect the torque and speed values recommended by the manufacturer, it should be remembered that the endomotor reads and controls the torque values through the feedback it receives through the instrument handle. However, the instrument is very flexible, especially near the top. The more flexible the instrument, the weaker the torque values are transmitted from the tip to the handle of the instrument, i.e. the endomotor cannot estimate the actual torque values to which the file is exposed in the apical third. This especially applies to instruments of small diameter and taper, for which lower torque values can be set [5, 44.]

Using a higher torque increases the activity of the instrument inside the root canal, but also increases the possibility of its jamming, deformation and fracture. In contrast, using a lower torque reduces the activity of the instrument, i.e., cutting the dentin and progression towards the apex. This can lead the operator to force the instrument in the canal, which in turn can cause it to fracture [71].

Working with different files requires adjusting torque and speed to prevent fracture and maintain efficiency. As the taper and diameter of the file increases, its stiffness also increases. As the stiffness of the file increases, the speed settings on the endomotor decrease and the torque values increase [72].

Instruments with longer shaft are more flexible, so lower torque values are set and speed is increased. The longer the instrument, the greater its resistance to torsional stresses. Accordingly, during instrumentation of narrow or curved canals, if the patient's condition allows, it is advisable to use instrument with longer shaft to increase its torsional resistance and reduce the likelihood of instrument fracture [73].

The conditions within the root canal also dictate the need for torque adjustment. In situations of instrumentation of curved and/or narrow and obliterated root canals, both speed and torque should be reduced [40].

With repeated use of the instrument, the value of its inherent torque decreases. Therefore, it is necessary to reduce the torque values on the endomotor. This will result in reduced cutting efficiency and longer canal instrumentation time, but also reduce the risk of instrument fracture [2].

Conclusion

Effective dentine removal, root canal integrity and original morphology preservation, and enhanced procedural safety are all impacted by torque modification during endodontic treatment. Dentists can increase endodontic therapy's efficacy, safety, and success by understanding and regulating torque. Despite the development of torque controlled devices, several challenges remain in endodontic practice. This first implies that root canal anatomy, instrument design, and operator skill are all variable. Future studies should focus on optimizing torque values for various clinical scenarios, enhancing instrument design, and improving torque measuring methods.

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