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Review article

Rationale for the use of low-torque endodontic motors in root canal instrumentation

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Abstract – Fracture of nickel-titanium rotary files is an iatrogenic error which can seriously jeopardize root canal therapy. If a high-torque motor is used, the instrument-specific limit-torque (fracture limit) is often exceeded, thus increasing the risk of intracanal failure. A possible solution to this problem is to use a low-torque endodontic motor which operates below these values. If the torque is set just below the limit of elasticity for each instrument, the risk of fracture is likely to be markedly reduced. The purpose of this paper was to discuss mechanical properties of NiTi rotary instruments, the rationale for selecting low torque values, and to use clinically a new endodontic motor (step-motor) which operates below the limit of elasticity of each rotary file. The step-motor was found to be helpful in reducing the risk of instrument fracture. Irreversible material damage (plastic deformation) and instrument fracture were rarely seen. Low-torque instrumentation also increased tactile sense and, consequently, mental awareness of rotary instrumentation.

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Key words: nickel-titanium alloy; root canal instrumentation; root canal preparation

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Endodontic preparation of curved canals represents a considerable problem for practitioners. When stainless steel instruments are used, there is a tendency for all preparation techniques to transport the prepared canal away from its original axis. Deviation from the original curvature can lead to procedural errors, such as ledge formation, zipping, stripping or perforations. As a consequence, new endodontic instruments and techniques have been introduced which serve to minimize these risks. More flexible nickel-titanium (NiTi) instruments for use in slow-speed high-torque handpieces have been developed and found to be efficient (1–2). The superelasticity of NiTi 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 (3).

The main problem with NiTi rotary instrumentation techniques probably is instrument failure. Intracanal instrument fracture is an iatrogenic error which can seriously jeopardize root canal therapy. Pruett et al. (4) have shown that the continuous cycle of tensile and compressive forces to which engine-driven instruments are subjected, produces a very destructive form of loading. Moreover, mechanical stress on NiTi rotary instruments is proportional with the motor torque. If a high-torque motor is used, the instrument-specific limit-torque (fracture limit) is often exceeded, thus increasing the risk of intracanal fracture. A possible solution to this problem might be to use a low-torque endodontic motor which operates below the maximum permissible limit-torque of each rotary instrument. If the torque is set just below the limit of elasticity (E) for each instrument, the risk of

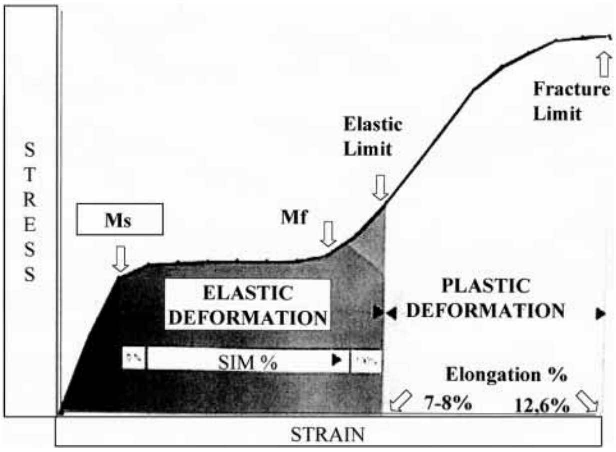

Fig. 1. Typical loading and unloading behaviour of superlastic NiTi (stress-strain curve) when subjected to tensile stress.

fracture is likely to be reduced to an extent far below what has been possible until now.

The purpose of the present paper was to discuss mechanical properties of NiTi rotary instruments, the rationale for selecting lower torque values, and to clinically evaluate a new endodontic motor (step-motor) which operates below the limit of elasticity of various types and sizes of instruments.

Superelastic NiTi rotary instruments

Shape memory alloys, such as nickel-titanium, 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 superlasticity (5). This latter property is important for the endodontic use. NiTi alloys can show a superlastic 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 immediately to undeformed austenite as soon as the stress is removed. This process elicits a springy, “rubberlike” elasticity from the alloy. The typical loading and unloading behaviour of superlastic NiTi (stress-strain curve) when subjected to tensile stress is shown in Figure 1.

The superelastic behaviour is typically represented by the martensitic yeald 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 (Fig. 2). This explains why NiTi 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 NiTi 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 & Morrow (6) have demonstrated that stainless steel wires undergo a much larger charge in force compared to the charge in force of NiTi wires when deflected an equivalent amount (spring rate). Clinically, this means that NiTi 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 NiTi, 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 (Fig. 1). In clinical practice, plastic deformation of NiTi rotary instruments

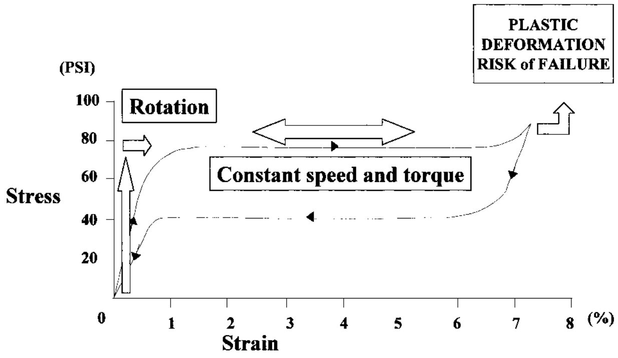

Fig. 2. Superlastic behaviour of NiTi alloy.

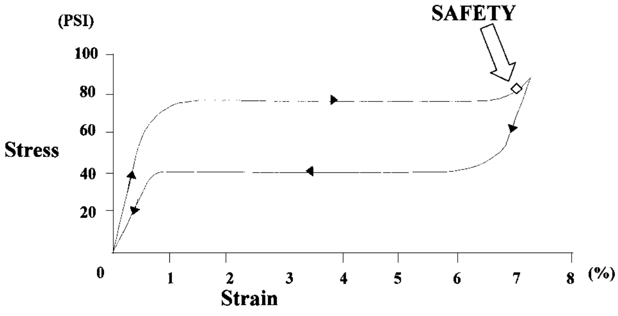

Fig. 3. Suggested low-torque setting (safety), slightly lower than the limit of elasticity.

should be avoided, because it may easily lead to fracture. As shown in Figure 1 the range of deformation allowed by the plastic field is twice as small as that allowed by the elastic field.

Extensive tension testing of NiTi wires has been done in the last few decades. Researchers have found that compression, torsion and flexural loading of NiTi 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 (7). NiTi endodontic instruments have been thoroughly investigated (8–10). Walia et al. (3) reported that no. 15 nickel-titanium files have two or three times more elastic flexibility and superior resistance to torsional fracture when compared with no.15 stainless steel files manufactured by the same process. Wolcott & Himel (9) have evaluated torsional properties of 0.04 tapered nickel-titanium rotary files according to ANSI/ADA specification number 28. From the results of their study, torque at fracture for sizes no. 15, no. 25 and no. 35 were, respectively: 0.22, 0.49 and 1.27 (Ncm). These are still low values, despite the superior resistance to torsional fracture of the alloy.

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

The previously mentioned values are interesting if we consider that the majority of conventional endodontic motors for NiTi rotary instrumentation are used at a higher torque setting (smallest values ranging approximately from 1 to 3.5 Ncm). This means that considerable stress is usually exerted on rotary instruments. This high stress is not clinically important in straight canals where the resistance of dentin removal is low. On the contrary, in curved and/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 NiTi rotary instrumentation has been accepted in the last decade by manufacturers, clinicians and researchers (11–13), leading 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 (14). 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 NiTi 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 and/or low-torque settings for different reasons. For example, if not electronically controlled the low-speed range of conventional motors is between 2000 and 4000 rpm, and the maximun speed is approximately 40 000 rpm. To permit operation at the optimum speed range for NiTi rotary instruments (i.e. 200–300 rpm) a large reduction factor is used. This reduces the speed, but the torque increases proportionally to the reduction ratio. The possibility of calibrating the handpieces is another important issue, which has recently been brought to the attention of the endodontists. Depending on the manufacturers 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. Some of the new motors, however, compensate for these losses by means of a calibration routine. The programmed torque is therefore always available as the operating torque.

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, Germany). 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 rigth-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 attemps 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.

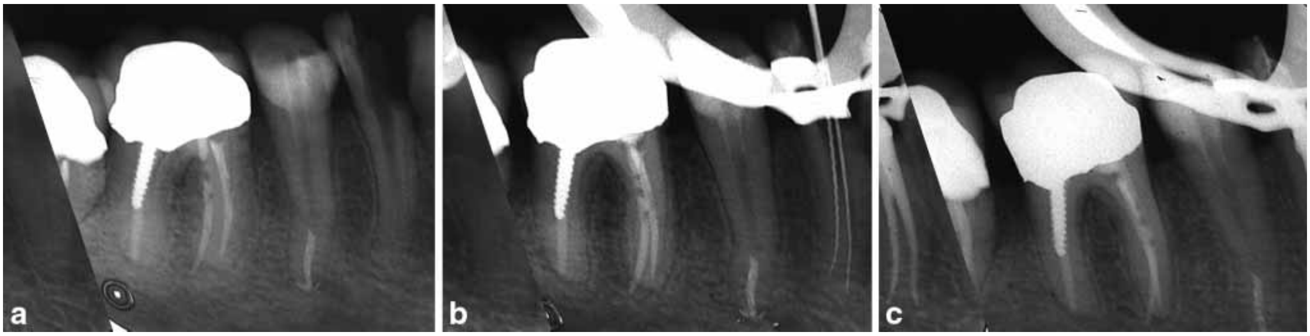

Fig. 4. (a) Pre-operative radiograph of mandibular premolar. The referring dentist was not able to locate and negotiate both root canals. (b) Intraoperative radiograph showing the working files placed to the apex in two different canals. (c) Final obturation shows proper shape. The canal preparation was performed using only NiTi rotary instrumentation.

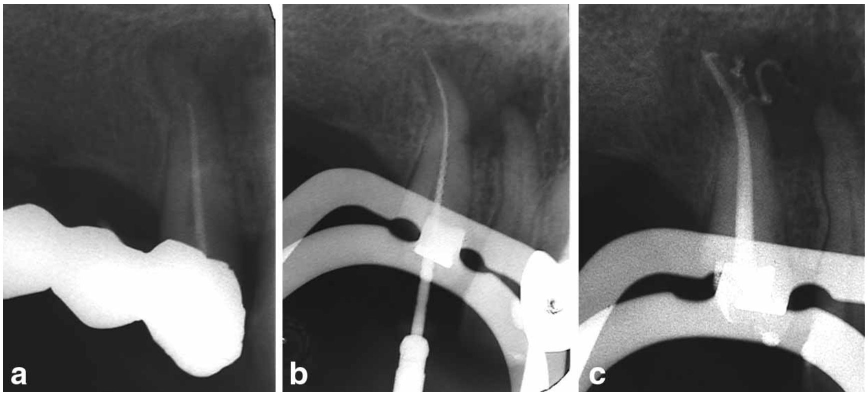

Fig. 5. (a) Inappropriate endodontic therapy which needs retreatment. (b) Obturation and ledge were bypassed and canal successfully negotiated to the apex using NiTi rotary instruments, which developed a continuously tapering canal preparation. (c) Retreatment completed. Multiple portals of exit were obturated using warm gutta-percha and zinc-eugenol based sealer.

Clinical evaluation

The EndoStepper motor has been used for six months in clinical endodontic practice by the author. ProFile instruments (Maillefer, Baillagues, Switzerland) and the crown-down instrumentation technique were used to prepare root canals in everyday practice. More than 300 teeth were instrumented using the step-motor. The motor provided many advantages. The main advantage was to dramatically increase tactile and mental awareness of rotary instrumentation. This was a fundamental step in reducing the risk of instrument fracture to a minimum. Moreover, an improved feel for the mechanics and limitations of NiTi rotary files was quickly developed. Low torque values mean low applied pressure on the root canal instruments. Vibrations and motor noise were negligible, and the instruments gently and efficiently negotiated the root canals within a reasonable period of time and with minimal mechanical stress (medium-easy canals). The instruments followed the curved canals (Fig. 4 a–c). No forcing was necessary, and the preselected values of torque and speed allowed the nickel-titanium files to do all the work (passive instrumentation). The increased tactile awareness was also important in retreatment cases, i.e. when iatrogenic errors such as ledges were encountered. The low-torque instrumentation was helpful in detecting canal blockage without the risk of intracanal fracture, since the instruments were backed out when a medium-low resistance was encountered. Fig. 5 a–c show a 0.04 tapered no. 20 rotary instrument bypassing the small ledge and the canal preparation was successfully completed by rotary instruments. The enhanced tactile awareness was also helpful in mantaining the original canal path while sequentially instrumenting the ledge.

Figures 6 and 7 show similar cases, i.e. premolars with a curvature in the apical thirds, but with important differences. The lower premolar presented a normal working length (20 mm) and the curvature was not severe (Fig. 6). Thus, the stress induced by anatomic complexities on the rotary instruments was not so high. It was possible to safely and efficiently negotiate the canal to the apex, using passive instrumentation and low torque values. The upper premolar on the other hand was a long tooth (working length=26

Fig. 6. Immediate post-treatment radiograph of curved lower premolar. Appropriate instrumentation with NiTi rotary instruments safely and efficiently developed a smoothly tapered canal.

Fig. 7. Final obturation of upper premolar with a severe apical curvature. Coronal enlargement was performed using NiTi rotary files. Apical preparation was completed by hand instrumentation. The apical constricture was kept small and in its original position.

mm), and also the curvature was more severe. Low torque values were selected, as in the previous case. However, the rotation inside the long, severe curvature induced much greater mechanical stress and the motor stopped. This safety feature was important, since it avoided plastic deformation and, probably, fracture of the rotary instruments. The canal preparation of the apical curvature was successfully completed with precurved, stainless steel hand-files, using great care.

The use of the step-motor was felt to be helpful in developing a new and more acute tactile sense. Moreover, when the motor stopped, it clearly was a warning that the instrument was subjected to high, possibly dangerous mechanical stress, and that continued use would be counter-productive.

Among the possible disadvantages it should be mentioned that with the use of the low-torque motor the cutting efficiency was reduced. This modification was the greatest for the smallest rotary files, when compared to traditional endodontic motors. Although this might not be a major problem, it could be irritating at first in that excessive resistance was felt in the canal, so that instrument penetration to the apex was blocked. In these cases, the usual operative sequences had to be modified. Usually additional crown-down enlargement was necessary before the apex could be reached. Coronal enlargement always decreases the overall canal curvature, and consequently reduces the mechanical stress on the instruments in the apical area. The case shown in Figures 8 a and 8 b) is an example how one can safely and efficiently prepare the delicate apical area by rotary instrumentation, following the above-described guidelines. Instrumentation time is not significantly increased, and the basic concept of using rotary files is not changed. The step-motor only gives the clinician a warning that caution should be exercised, and that a different operative se-

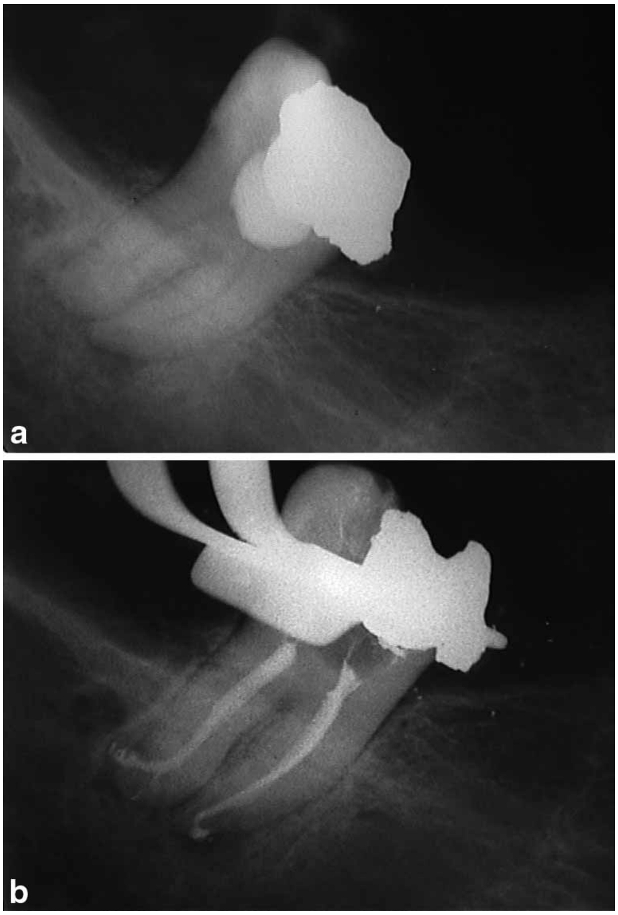

Fig. 8. (a) The third molar to be treated endodontically for fixed bridge restoration. (b) Post-treatment radiograph shows proper root canal preparation (continuously tapering form) through crown-down NiTi rotary instrumentation and recapitulations.

quence must be selected to avoid excessive stress on the instrument.

Clinical conclusion

Based on the author's clinical experience, it appears that the step-motor will help to reduce the rate of NiTi rotary instrument fracture. Due to the fact that a specific limit-torque (close to the limit of elasticity) can be set for each instrument size and type, and that the motor stops if it is loaded up to this instrument-specific limit-torque, it was a rare occurrence to see irreversible material damage (plastic deformation) and instrument fractures.

The introduction of the step-motor in root canal treatment was felt to be a promising development. Clearly the use of the motor warrants that proper experimental studies and clinical trials are carried out in order to determine both effectiveness and safety of rotary instrumentation with specific limit-torque settings.

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