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Rotary Instruments in Nickel Titanium

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Over the last few years endodontics has undergone a complete revolution with the introduction of the NiTi alloy for the manufacture of initially manual and then rotary endodontic instruments. The extraordinary characteristics of superelasticity and strength of the NiTi alloy[83,84] have made it possible to manufacture rotary instruments with double, triple and quadruple taper compared to the traditional manual instruments (Fig. 18.1).[26]

This has made it possible to achieve perfect shaping with the use of very few instruments[22,58] in a short period of time and without the need for above average skills on the part of the operator.

CHARACTERISTICS OF NITI ALLOY

The NiTi alloy came to the fore when used at the beginning of the 60's by W. H. Buehler in a space program of the Naval Ordnance Laboratory at Silversprings, Maryland, USA.[18]

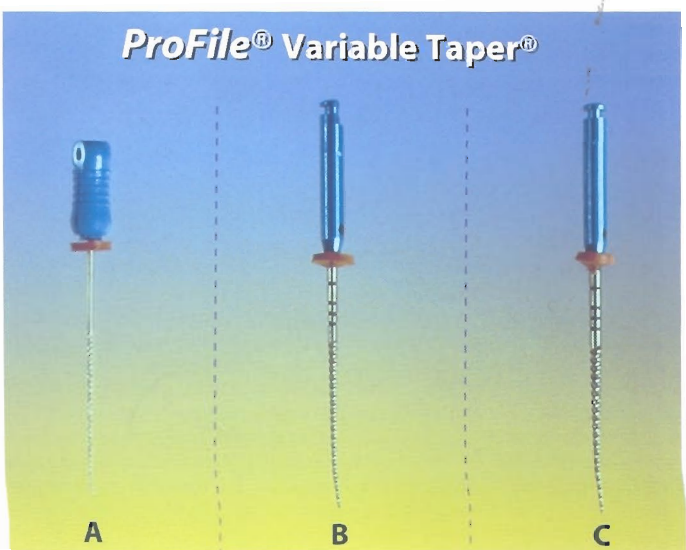


Fig. 18.1. **A.** ProFile hand file .02 taper. **B.** ProFile rotary instruments .04 taper. **C.** ProFile rotary instruments .06 taper

The alloy was called Nitinol, an acronym for the elements from which the material was composed: ni for nickel, ti for Titanium and nol from the Naval Ordnance Laboratory.

It was introduced into dentistry in 1971 by Andreasen et al.[1-3] in order to create orthodontic wires.

The NiTi alloy belongs to the family of the Nickel and Titanium intermetallic alloys, characterized by two properties which distinguish them, the memory of shape and superelasticity.[17]

Shape memory

By shape memory we mean the capacity of NiTi alloys to reacquire its initial shape through heating after strain.[18] This property is utilized in orthodontics but not in endodontics.

Superelasticity

We define elasticity as the property of bodies to deform by the action of external forces and once these external forces cease the ability to return to the original state. There is a limit which is defined "elastic limit", beyond which there is a component of plastic strain which can no longer be recouped by the elimination of external forces. For example if we compare two wires of equal cross section, one in stainless steel and one in NiTi, we can better understand the extraordinary property of superelasticity which NiTi has. If we apply a moment of force to a stainless steel wire that is able to produce an angular deformation of 80°, when the moment ends a permanent angular deformation of 60° will

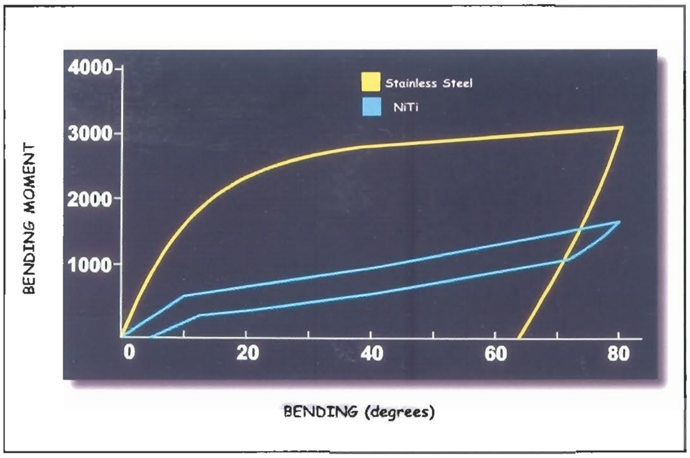


Fig. 18.2. Strain-stress diagram.

remain (Fig. 18.2). It can be deduced that the stainless steel wire has an elastic deformation limit of 20° above which every deformation becomes permanent.

If we apply a bending moment which is able to produce a deformation of 80° to a NiTi alloy wire of equal cross section, when the moment ends a permanent angular deformation of less than 5° will remain. The wire in NiTi will undergo deformation which is almost completely elastic, leaving a minimum permanent deformation (Fig. 18.2).[11,70,83]

This characteristic (superelasticity) is particularly evident when for example, using a finger, we try to bend two identical endodontic instruments, one in stainless steel, the other in NiTi. The stainless steel endodontic instrument presents a higher stiffness while the NiTi instrument is particularly compliant. The use of endodontic instruments in NiTi is particularly advantageous for shaping the canal system in harmony with the original anatomy.

Strength

Walia et al.[83] and Camps et al.[20] have demonstrated that files in NiTi were much more resistant to clockwise and counter-clockwise torsional stress compared with files of equal size but in stainless steel. This elevated strength of the NiTi alloy has made it possible to manufacture rotary instruments that have greatly simplified the shaping of the root canal system.

Metallurgy of nickel-titanium alloys

The NiTi alloy used in root canal treatment contains approximately 56% (in weight) of Nickel and 44% (in weight) of Titanium. In some NiTi alloys, a small percentage (<2% in weight) of Nickel can be substituted by cobalt.[72] The resultant combination is a one-to-one atomic ratio (equiatomic) of the major components (Ni and Ti). This alloy has proved to be among the most biocompatible materials and it is extremely resistant to corrosion.[72] As we have previously said, NiTi belongs to the family of inter-metallic alloys. This means that NiTi alloy can exist in various crystallographic forms, with distinct phases and different mechanical properties: austenitic, transformation and martensitic (Fig. 18.3).[85]

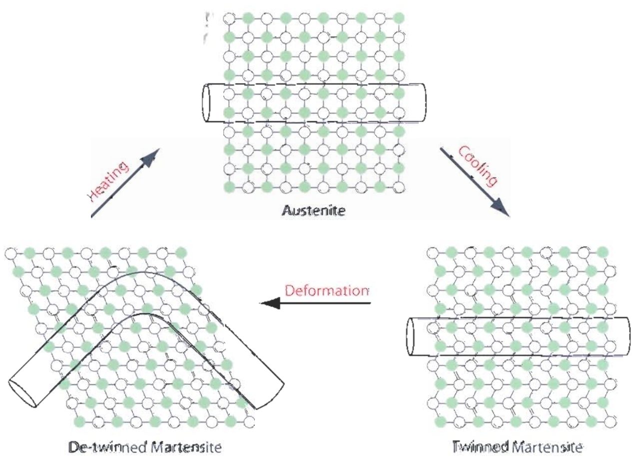


Fig. 18.3. Diagrammatic illustration of the martensitic transformation and shape memory effects of NiTi alloy (By Thompson S.A.; Int. Endod. J. 33:297, 2000).

1) AUSTENITIC PHASE (A): with body-centred cubic lattice. It's the most stable phase.
2) MARTENSITIC PHASE (M): with hexagonal compact lattice. It's the most unstable and ductile phase.
3) TRANSFORMATION PHASE (T): it is made up of a series of intermediate phases which transform one into the other, causing a movement of the Ni and Ti atoms onto opposite and parallel crystalline levels; this doesn't entail a variation of the crystallographic shape.

Each crystalline phase exists in a specific temperature interval.[53] The transition from one phase to the other is possible only within a temperature range including those at the beginning and at the end of transformation (Fig. 18.4):

As: temperature at the start of Austenitic transformation

Af: temperature at the end of Austenitic transformation

Ms: temperature at the start of Martensitic transformation

Mf: temperature at the end of Martensitic transformation

Cooling the alloy below the T.T.R. (transformation temperature range), besides the crystalline modification, we also have a change of its physical properties with an increase in malleability (Martensitic phase). Raising the temperature above the T.T.R. one returns to the energetically more stable phase with a body-centred cubic lattice (Austenitic phase).

Such phase changes can also be induced by the application of deformation states, as happens with NiTi endodontic instruments during their work inside the root canals.[72]

The NiTi alloy therefore has a strongly non-linear mechanical behaviour.[55,85,86] This means that there isn't a (linear) proportional correspondence between stresses and strains.

The NiTi alloys are characterized by a stress-distorsion diagram which is divided into three distinct portions, corresponding to the three crystalline phases: austenitic, transformation, martensitic (Fig. 18.5).

The most performing phase of the NiTi endodontic instruments corresponds to the second section of the diagram (transformation phase), where we have the passage between the more stable crystalline phase (the austenitic type), and the more unstable phase (the martensitic type), where the alloy manifests important distorsions which culminate firstly in the yield point and then in the fracture.[2,72]

In the transformation phase the characteristics of superelasticity appear. If we observe the diagram we see how in this phase the strains can increase while the stresses remain constant. The alloy can deform over quite a wide range while the fatigue damage that accumulates remains constant. It's like having a motor car that has the extraordinary characteristic of being able to travel from 60 km/h to 130 km/h using the same quantity of the fuel.

It is evident that the more the alloy works in this phase, the more the characteristics of compliance and strength are established.[35] The Niti rotary endodontic instruments will thus be able to shape the root canal following the original root canal anatomy even if complex, without reaching elevated values of stress.[14,39]

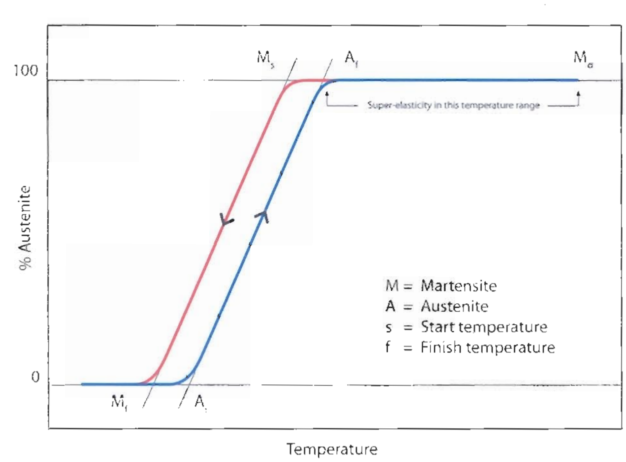


Fig. 18.4. Hysteresis of martensitic transformation (By Thompson S.A.; Int. Endod. J. 33:297, 2000).

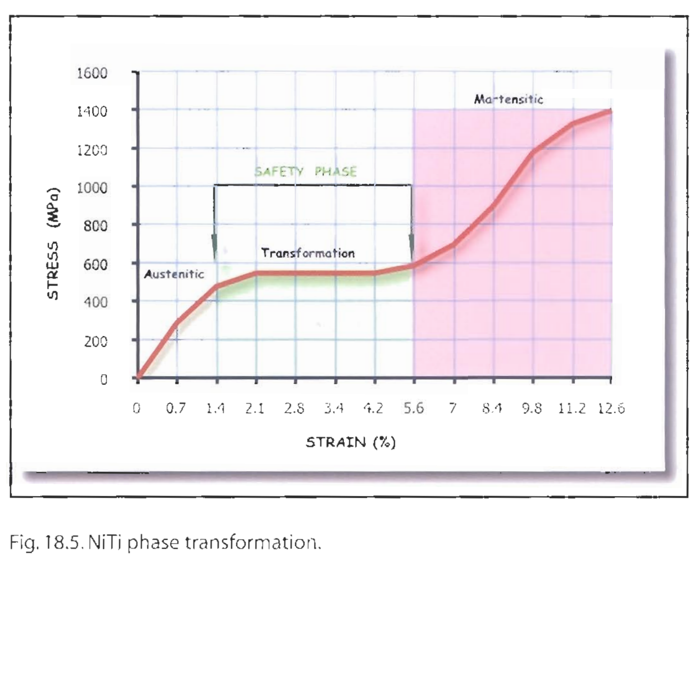


Fig. 18.5. NiTi phase transformation.

Advantages

In 1974 H. Schilder[69] stated what the mechanical and biological objectives to be followed to achieve a correct cleaning and shaping of the root canal system. From that time until a few years ago, numerous manual techniques have been proposed and many endodontic stainless steel instruments (manual or rotary) have been commercialized.[31,50,63] There are two disadvantages:

1) the stainless steel with which the endodontic instruments were and are still made, is a material with an elevated stiffness which often doesn't adapt well to the convoluted root canals
2) the stainless steel instruments available are almost cylindrical (.02 taper). To achieve a tapering conical shape required laborious operative sequences, which demanded good skill and a lot of patience.

The introduction of the NiTi alloy has allowed one to simultaneously solve these two problems. The superelasticity and the strength of the NiTi alloy has made it possible to obtain rotating instruments with a taper which is double, triple and beyond with respect to the standard .02 taper of the stainless steel hand instruments. The greater taper has drastically reduced the number of instruments needed to shape a canal. The superelasticity has furthermore made it possible to carry out extremely conservative shapes, better centered, with less canal transportation and therefore with more respect of the original anatomy.[15,33,37,41,56,62,68,73-78,82]

The strength of the NiTi alloy has made it possible to mechanize these endodontic instruments with an increased taper, making it possible for all the Operators (even those without exceptional skill) to obtain perfect shapings and in a short period of time.

To better understand the enormous differences between the shapes obtained with stainless steel endodontic instruments and those obtained with NiTi rotary instruments with a greater taper it is useful to compare the cross-sections of the two canals of mesial roots of lower first molars, at the level of the coronal one third, before and after instrumentation with each technique.

The canals shaped with stainless steel files using the step back technique are dangerously transported towards the bifurcation. J.B. Roane[60] states that this was caused by the "restoring force" of the file which, even if precurved, tries to regain its straight primitive shape. Observing the shape of the cross section of the canal, it is evident how the large and oval shape is the expression of the dynamic movement of the file in the space and of the "restoring force" and not of the cross section of the instrument that has worked at that level. The shape is not centered in the original canal (Fig. 18.6). The curves are straightened and consequently the shape in those areas is much larger than the instrument cross-section, which has worked at that point. These considerations are not only important to avoid excessive weakening of some canal walls, with the risk of creating perforations (stripping), but they are also very important in order to obtain a truely three dimensional obturation of the root canal system. Indeed, the gutta-percha cone having a round cross-section adapts badly to an oval shaped canal. The condensation forces of the warm gutta-percha during the obturation will be dissipated filling the empty spaces between the round gutta-percha cone and the oval canal and consequently the root canal system will be underfilled (Fig. 18.7). If we analyze the result of the

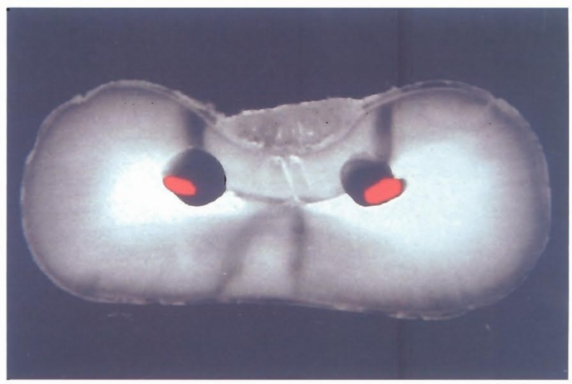


Fig. 18.6. Cross section of the mesial root of the lower first molar at the coronal third level: in red is the original canal, in black the canal shaped with hand files in steel using the step-back technique. The shaped canals are enlarged in an oval shape with transportation towards the furcation.

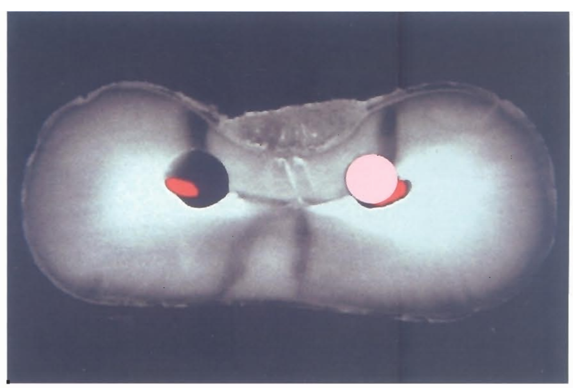


Fig. 18.7. In pink the cross-section of a gutta-percha cone adapted to the canal. Note the gap between the gutta-percha cone and the oval shaped canal.

work done by the NiTi rotary instruments, in this case Profile .06, still in a mesial root of a lower first molar, before and after instrumentation we see how the shape developed exactly concentrically with respect to the original canal, thanks to the extraordinary compliance of these instruments. The shaped canals are perfectly round, an expression of the corresponding NiTi rotary instrument cross section that has worked at that level of the canal (Fig. 18.8). As has previously been said, this is of extreme importance in the obturation phase. The gutta-percha cone will thus have intimate contact with the canal walls and the compacting forces will be exploited fully to three dimentionally fill the canal system (Fig. 18.9).

Fig. 18.8. Cross section of the mesial root of a lower first molar at the coronal third level: in red the original canal, in grey the canal shaped with a .06 ProFile rotary instrument. The canals are shaped with minimal enlargement and have a round form. The shaping was developed centrally in the original canal.

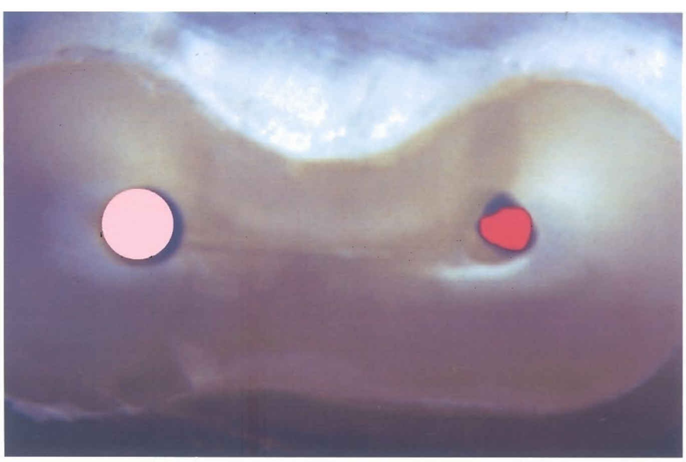


Fig. 18.9. In pink a cross-section of the gutta-percha cone adapted to the canal. Note the perfect adaptation of the gutta-percha in a canal shaped to a round form.

FUNCTIONING OF THE NITI ROTARY INSTRUMENTS

Let us now analize the functioning of the NiTi rotary instruments during the shaping of the canal system.

The states of stress to which the NiTi rotary instrument is cyclically subjected are responsable for the strain (deterioration).

The strain is determined by two principal types of stresses: bending stress and torsional stress.

Torsional stress

Torsional stresses are very harmful and if they are of elevated intensity, they rapidly cause the fracture of the instrument. This generally happens in three situations:

1) when a large surface of the instrument rubs excessively against the canal walls (taper lock)
2) when the instrument tip is larger than the canal section to be shaped
3) when the operator exerts excessive pressure on the handpiece

Unlike the bending stresses which are largely dependent of the original anatomy of the canal, and therefore not easily modified, we can intervene on the torsional stresses partially reducing the effect (impact) through the correct use of the instruments and some other techniques.

Large contact surface

The cutting action and therefore the blade dentine contact surface must be reduced to a fraction of the working part of the NiTi rotary instrument with greater taper. The larger the blade-dentine contact surface the higher the torque required to allow the rotation of the instrument and therefore the cutting of the dentine[51] (Fig. 18.10). This means an elevated torsional stress which the alloy stores, in this way rapidly reducing the life of the instrument. Furthermore if the torque values necessary to make the instrument rotate exceed the values of the maximum torque moment that the instrument can endure, the instrument distorts and fractures.

To avoid this dramatic inconveniece the NiTi rotary instruments with greater taper must be utilized with the crown-down technique.[24,25]

Blum et al.[10] have demontrated that the NiTi rotary instruments are subjected to lower stress levels if utilized with the crown-down technique rather than if utilized with the step-back technique.

Even the cutting ability of the instrument is more efficient if used with the crown-down technique.[43,69]

The instruments must be used in sequence from the largest to the smallest (Fig. 18.11).

The NiTi rotary instruments with greater taper once introduced into the canal creates a shape similar to its

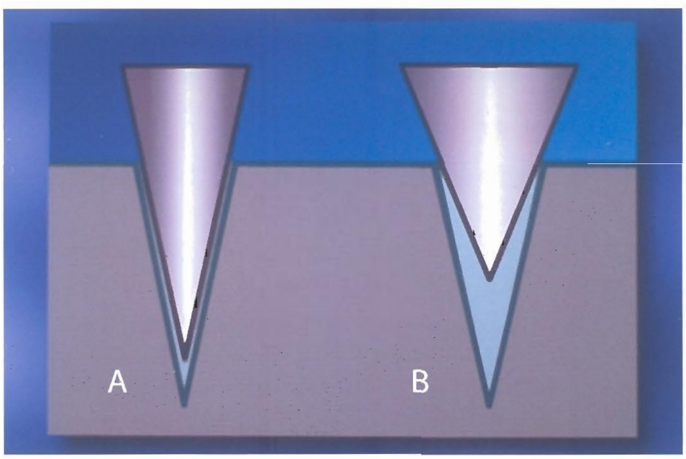


Fig. 18.10. **A.** The blade-dentine surface contact is very large. The torque required to maintain a constant rotational speed of the instrument will therefore also need to be very large. **B.** The blade-dentine surface contact is very small: the torque required to maintain a constant rotational speed of the instrument will therefore also be small (Courtesy of Dentsply Maillefer).

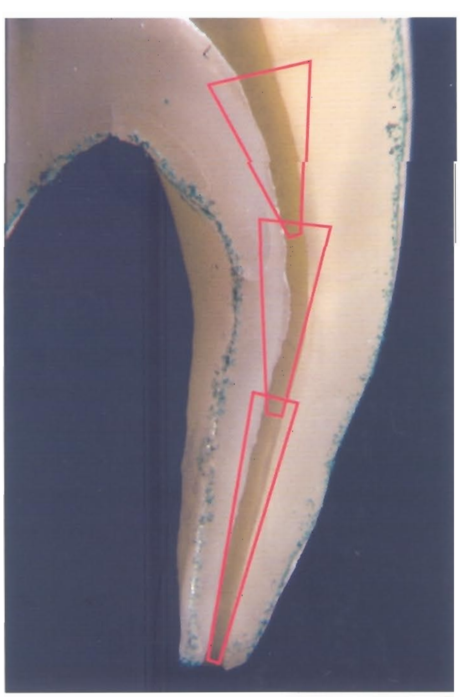


Fig. 18.11. Crown-down technique.

own shape. It will go forward in the canal as far as the original anatomy will make it possible. The next smaller instrument will descend more apically and will no longer work in the areas where the previous instrument, which was larger, had already shaped the canal. In this way the canal will be prepared in successive corono-apical sections that fit one into the other. The instruments work in this way using only a small portion of their working surface.

Another element that can increase the surface contact between canal wall and instrument and so increase the torsional stress, is the accumulation of dentinal debris between the blades of the instrument. This dentinal mud accummulates in large quantities between the blades and if not removed, compacts more and more during successive use of the instrument.

Not only the blade surfaces of the working part come into contact with the canal walls but also the dentinal mud compacted between the blades. The working part of the instrument in this way is transformed into an entire contact surface, as though it is a uniform frustum of cone.

This causes an immediate and notable increase in torsional stress.

The operator must become aware of when the speed with which the NiTi rotary instrument advances inside the canal starts to diminish, this is a sign of an excessive accumulation of debris between the blades.

It is therefore important, after every passage, to methodically clean the blades of the NiTi rotary instruments having a greater taper.

Instrument tip and canal width

At the moment the vast majority of rotary NiTi instruments with greater taper have a non cutting tip (non active) (Fig. 18.12) or moderately cutting (moderately active) (Fig. 18.13).

This is to prevent the formation of ledges, false paths or apical foramen transport. If on the one hand the non active or moderately active tip, allows one to avoid the above mentioned errors, on the other hand it presents one with another problem. If the tip with poor or non cutting ability encounters a canal or a canal portion with a smaller cross-section, the tip advances with great difficulty. Torsional stress increases enormously and if the tip binds and the gearing of the motor is higher than the maximum torque that the instrument can withstand, this immediately undergoes plastic strain and then fractures.[10] This condition, to-

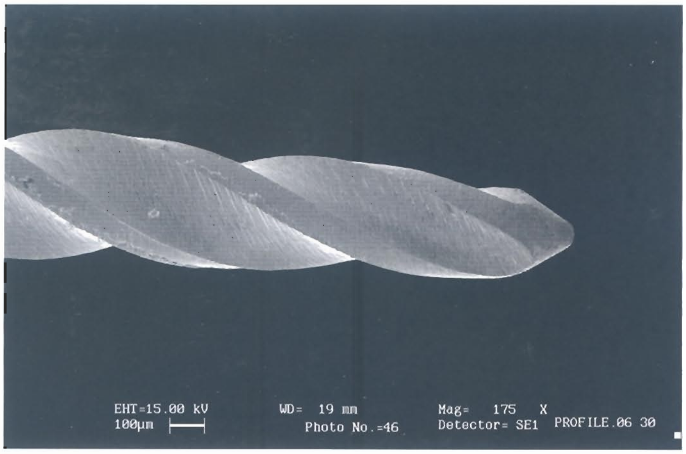


Fig. 18.12. ProFile .06: particulars of the tip.

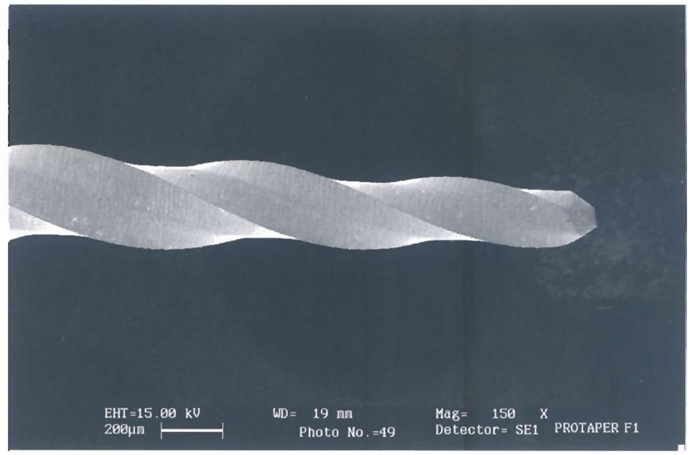


Fig. 18.13. ProTaper: particulars of the tip.

gether with the complexity of the original anatomy are the major factors responsable for the fracture inside the canals of the NiTi rotary instruments with increased taper. It is therefore essential to manually create (manual pre-flaring) a glide path for the tip of the greater taper NiTi rotary instrument that will have to be utilized.[65]

Initially a brief manual instrumentation, allows us to:

- drastically reduce the torsional stresses, by creating a canal at least as large as the diameter of the NiTi rotary instrument tip with greater taper, that will be used successively
- interpret the original anatomy.

To understand the importance of the manual pre-flaring, research carried out by E. Berutti et al.[7] is meaningful. The study calculated how many endodontic simulators (Endo-Training-Block, Maillefer, with a 0.15 mm canal diameter and .02 taper), the first NiTi rotary instrument of the Protaper series S1 could shape, before breaking, under two separate conditions: with and without manual pre-flaring.

The S1 has a tip diameter of 0.17 mm. The endodontic motor utilized was the Tecnika (ATR) with the following characteristics: 300 rpm speed and 100% torque corrisponding to 68 Nmm.

In the first group (group A) S1 shaped on average (reached the apex) 10 new endodontic simulators before breaking.

In the second trial group (group B) a brief pre-flaring was achieved manually using 3 files size 10, 15 in stainless steel and 20 in NiTi, so as to enlarge the apical foramen to a greater dimension than the calibre of the instrument being used.

The aim of manual pre-flaring was to probe the apex with a 20 NiTi file. By so doing a guide path was achieved (canal diameter after the manual pre-flaring was equal to 0.20 mm and .02 taper) for the tip of the NiTi rotary instrument (the S1 has a 0.17 mm tip diameter). In these conditions the S1 was able to shape (reach the apex) on average 59 endodontic simulators before breaking (Fig. 18.14). The manual pre-flaring avoided subjecting the tip of the S1 to torsion while trying to make a path in a canal with a very small cross-section. In this way one created a guide path for the tip of the NiTi rotary instrument thereby enormously reducing the torsional stress that the instrument experiences and in so doing increases its life span six fold. This means a cost reduction and a reduction of the fracture risks of the instrument in the canal. In recent years scientific studies have confirmed the importan-

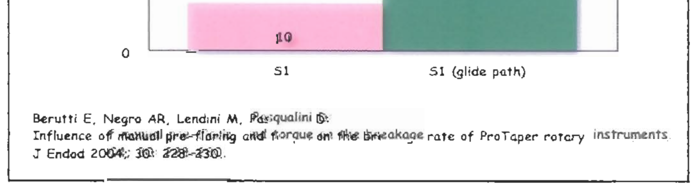


Fig. 18.14. Diagram illustrating the number of plastic blocks shaped by the ProTaper S1 before instrument breakage. In pink the number of virgin plastic blocks shaped. In green the number of plastic blocks shaped after creating a glide path using a # 20 hand file.

ce of manual pre-flaring. Roland at al.[61] showed on extracted human teeth that manual pre-flaring significantly reduced the risk of fracture of the Profile .04 inside the canal. Blum J.Y. et al.[12] used the Endographe, an instrument able to measure, register and graphically reproduce the vertical forces as well the torque values that develop when using the Protaper instruments (Dentsply Maillefer, Ballaigues, Switzerland) in the root canals of extracted teeth with different anatomy.

The Authors showed that manual pre-flaring is essential for the safe use of NiTi rotary instruments and that it significantly reduces the time that each instrument is used and consequently the total time for shaping the root canal. Peters O. A. et al.[57] did not record any Protaper fractures in the canals of extracted human molars when sufficient manual pre-flaring was carried out.

We can therefore conclude that manual pre-flaring is an essential and irremissible phase of canal shaping with NiTi rotary instruments. This guarantees a reduced fracture risk of the NiTi rotary instruments, reduced working time and not least of all also allows us to mentally develop a three dimenstional image of the canal system which we have to shape. This is decisive in making the correct operative sequence which will follow (Fig. 18.15).

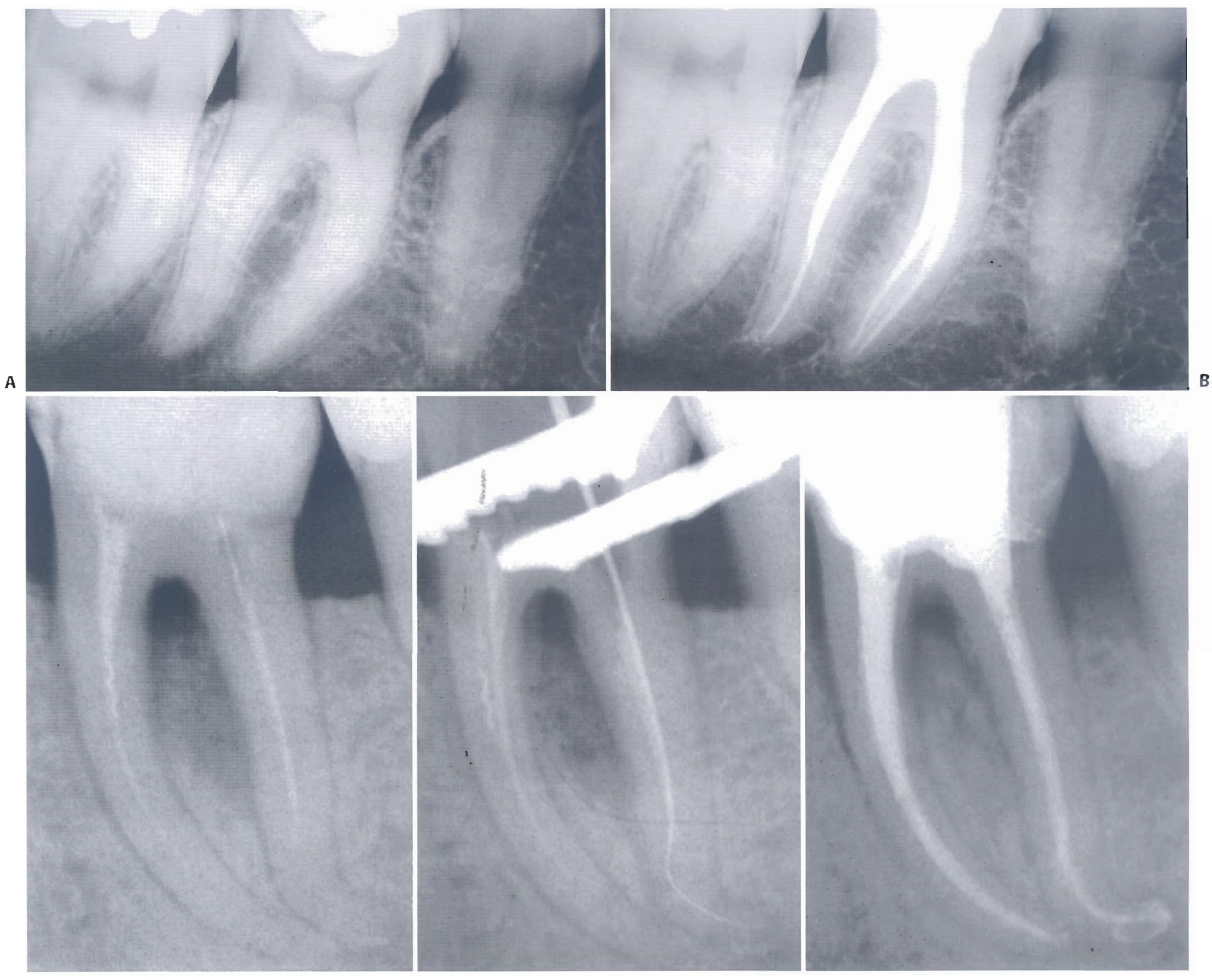


Fig.15. Clinical cases of teeth with calcified canals where the preshaping with hand files is very important. **A.** Preoperative radiograph of the lower right first molar. **B.** Postoperative radiograph (E. Berutti). **C.** Preoperative radiograph of lower left first molar. **D.** Radiograph to check the working length of the distal canal. **E.** Postoperative radiograph (G. Cantatore).

Excessive manual pressure on the handpiece

An excessive manual pressure on the handpiece causes a notable increase in the friction between the instrument and the canal wall. The rotation velocity reduces and the gearing immediately increases to keep the velocity constant.

Consequently at the instrument tip level and /or on the surfaces where the instrument makes contact with the canal walls, very high torsional stresses are generated which could immediately cause the fracture of the instrument.[79]

Bending stresses

The bending stresses are the main causes of strain[28,58,71] and they depend on the original anatomy of the canal which, with its curves, forces the instrument to bend as it passes through it. Pruett et al.[58] have demonstrated that the curve radius, the bend angle and the largeness of the instrument are the factors responsible for the fractures due to bending fatigue.

If one imagines a stationary rotary instrument inside a curved canal it follows that it will be subjected to two different types of stresses (Fig. 18.16):

- compression stress on the internal surface of the curve
- tensile stress on the external surfaces of the curve.

In the central part of the instrument, there exists, theoretically speaking, a neutral plane where stresses don't exist. This divides the two different types of stress. The tensile and the compression stresses are at their highest in the section where the curve radius is at its minimum, then it reduces gradually as one gets further away from the area of maximum stress (Fig. 18.17).

If one imagines the instrument in motion (continual rotation) all the above mentioned stresses will continuously change with every revolution.[67]

We will have the continuous passing from tension to compression, from compression to tension and so on, in other words the alloy will be continuously subjected to stress of the opposite type.

Therefore it is important to never stop inside a curved canal with the instrument in motion.[47] The instrument portion at the section with the least curve radius will be extremely stressed and the alloy will experience an excessive quantity of stress, creating at that point, a damaged area.[58]

We must imagine the NiTi rotary instrument as made up of millions of small NiTi alloy bricks. Each brick will experience quantities of strain perfectly proportional to the amount of stress it has been subjected to. It is therefore important to know how to utilize the NiTi rotary instrument in the best way possible, distributing the stresses in a homogeneous way throughout the alloy, thereby not creating areas of damage.[81] Consequently the instrument must be introduced, already rotating, into the canal and advanced in-

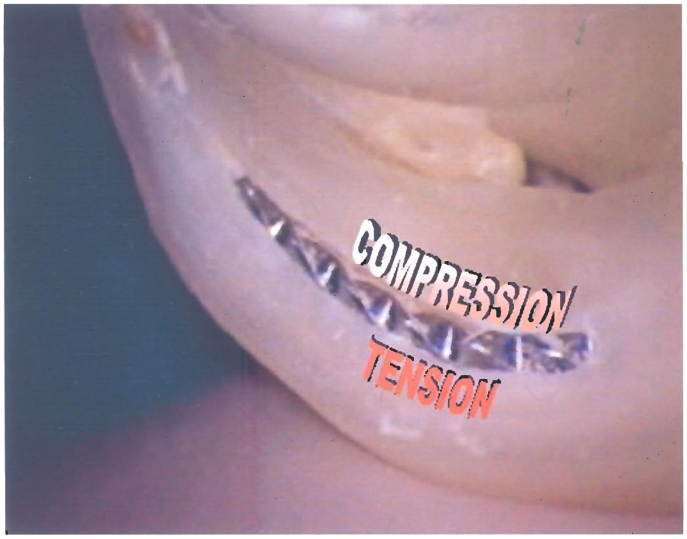


Fig. 18.16. Bending stress: on the internal aspect of an instrument rotating in a curved canal compression develops while on the external aspect tension develops. In the centre of the instrument there is theoretically a neutral zone that does not develop stresses.

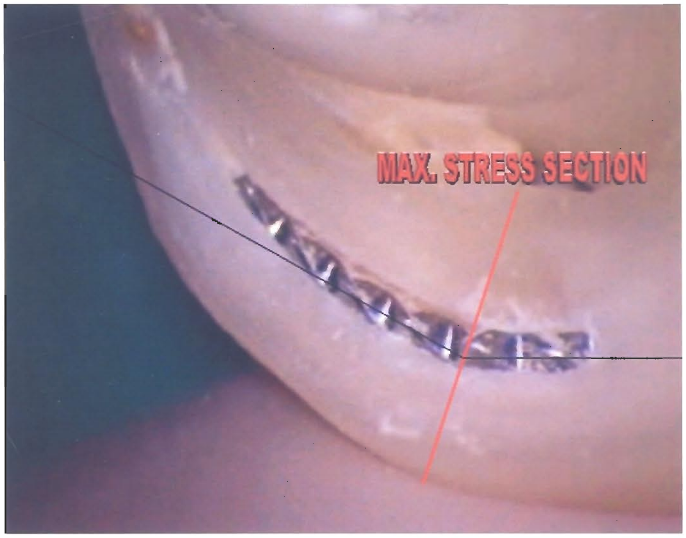


Fig. 18.17. In the rotary Niti instrument working in a curved canal the tension and compression are at a maximum in correspondence to the cross section of the instrument where the radius of the curvature is the least.

to its interior with light manual pressure. The movement must be fluid, continuous, without interruption. The operator must become aware of when the instrument has terminated its penetration further into the canal and can go no further. The operator must immediately extract the instrument, always doing so slowly, with a continuous movement, without ever interrupting its rotation.

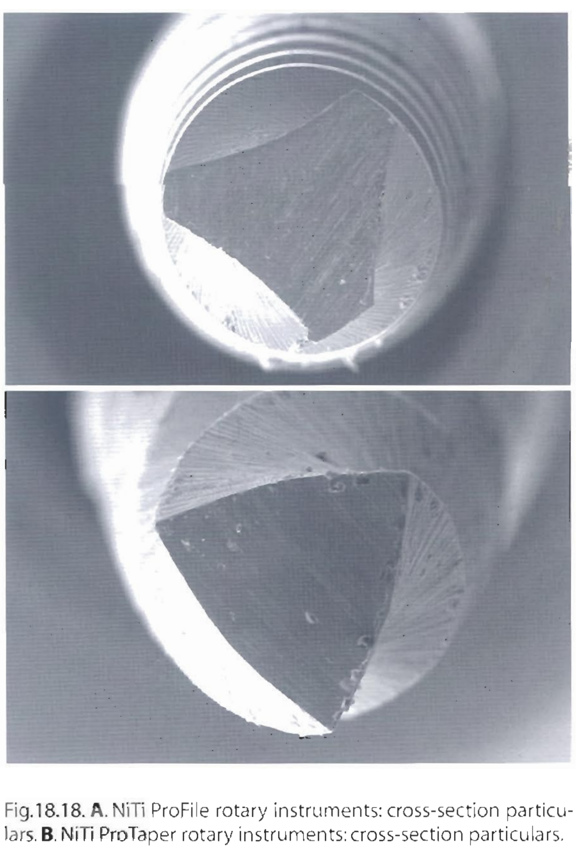
IMPORTANCE OF THE SECTION OF THE NITI ROTARY INSTRUMENT

The NiTi rotary instrument with greater taper works inside the canal in continuous rotation and is therefore subjected to continual and variable stresses based on the original canal anatomy and on the hardness of the dentine which it has to cut.[70]

The ideal NiTi rotary instrument should therefore be sufficiently compliant to be able to create a centrifugal shaping of the canal and to be sufficiently resistant to withstand the torsional and bending stresses which occur during its work. Its section is very important, because it directly determines the strength characteristics to the different stresses and the ability to cut the dentine is determined by the shape of the blades.[21] To have a better understanding of how the section is able to condition the way in which the NiTi rotary instrument performs, it is interesting to analize the research carried out by Berutti et al.[6]

The authors have analized the mechanical behaviours of two sections, the ProFile (U File) and the ProTaper (convex triangular section) through the method of finite element analysis (Fig.18.18). This foresees, first the realisation of mathematical models of the structures to be analized, then the attribution of the physical characteristics of the constitutive material to the mathematical models and finally the imposition of work conditions. The method makes it possible to highlight the different degrees of stress through the colorimetric scale and their distribution in the analized models.

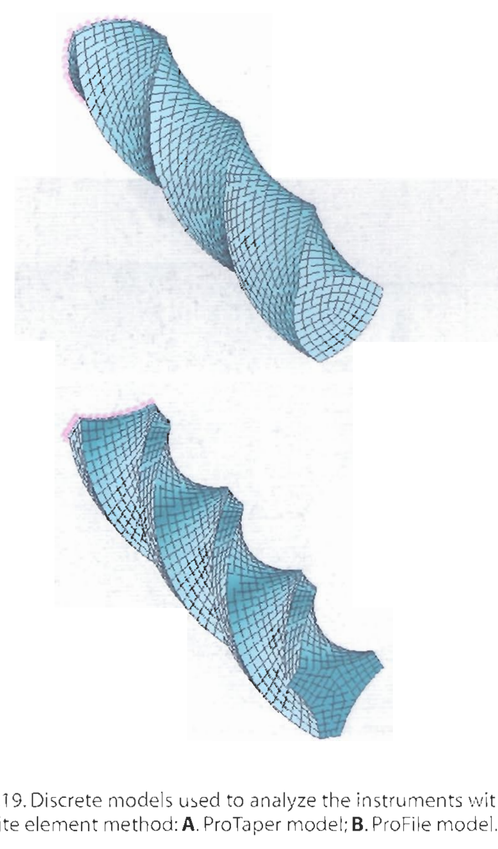
In this research stresses were compared resulting from torsion and bending moments of two cylindrical models with a diameter of 0.4 mm, one with a ProFile section the other with a ProTaper section (Fig. 18.19). First the torsion stresses were analized applying to both models a 2.5 Nmm torque. The distribution of torsion stresses in the model with the ProTaper section resulted regular and uniform, while in the ProFile



A

B

Fig.18.18. **A.** NiTi ProFile rotary instruments: cross-section particulars. **B.** NiTi ProTaper rotary instruments: cross-section particulars.



A

B

Fig. 18.19. Discrete models used to analyze the instruments with the finite element method: **A.** ProTaper model; **B.** ProFile model.

section model, high stress peaks were evidenced at the base of the blade grooves and their distribution was heterogeneous (Fig. 18.20).

Even the intensity of the stresses was in favour of the model with the ProTaper section that was working in its more superficial portion in the superelastic field (transformation phase).

The ProFile section model instead reached more elevated stresses concentrated at the base of the blade grooves, where the material had lost the characteristics of superelasticity (martensitic phase). It therefore appears evident how in the ProTaper section model the stress reach a lower intensity and a homogeneous distribution.

Then the bending stresses were analized, applying to both models a 2.9 Nmm bending moment. Even in this instance the analysis of the stresses in the two models showed how the model with the ProTaper section under equal loading reached lower stress levels which were homogeneously distributed over all the surfaces compared to the ProFile section model, which always showed higher stress values that were concentrated at the base of the blade grooves (Fig. 18.21).

A further important fact which emerges from this work is that the ProTaper section presents a larger area of almost 30% compared to the ProFile section. This translates into a lesser mass of the ProFile section compared to the ProTaper section and therefore in a moment of bending inertia noticibly lower for the ProFile section, which therefore results more compliant than the ProTaper section. The section therefore, with its shape conditions the more determinant characteristics of the NiTi rotary instruments namely: strength and compliance.

The variety of the instruments at our disposal are increasing all the time. It will be the operator who, on the basis of the endodontic anatomy to be shaped, will chose the correct operative sequence.

One must not think of the NiTi rotary instrument system as a closed system. Once the operator has interpreted the endodontic anatomy he can substitute some instruments of one system with others of another system if these should prove to be more suitable in obtaining a correct shaping.

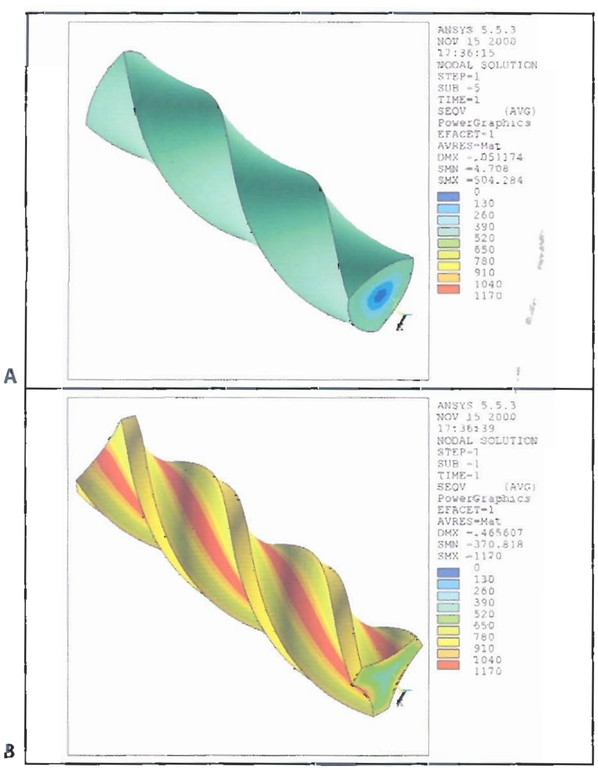


Fig. 18.20. Distribution of Von Mises stresses with an applied torque of 2.5 Nmm. **A.** One notes with a ProTaper model the even and homogenous distribution of the stresses (transformation phase). **B.** One notes with the ProFile model the high stress level (martensitic phase) reached in the base of the blade troughs.

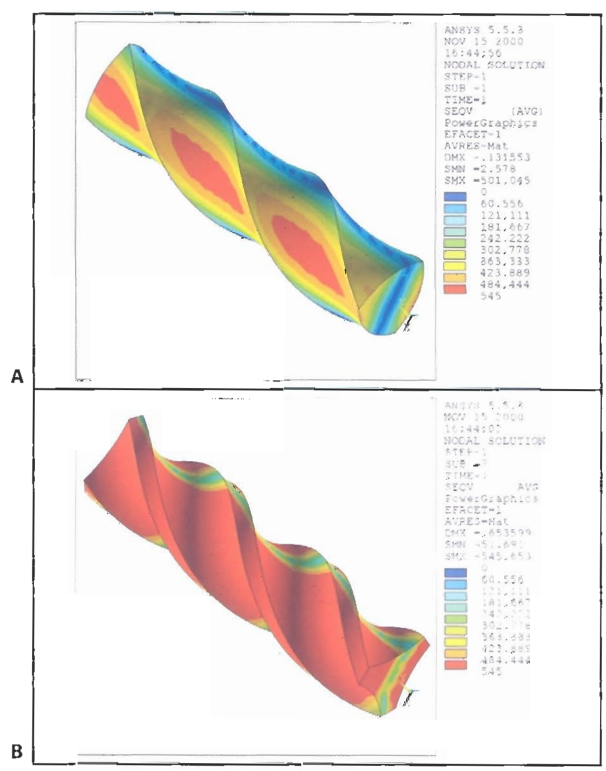


Fig. 18.21. Distribution of Von Mises stresses with an applied bending moment of 2.9 Nmm. **A.** One notes with the ProTaper model the low level of tensions (transformation phase) reached and their even and homogenous distribution. **B.** One notes with the ProFile model the high level of tensions (martensitic phase) concentrated on the base of the blade troughs.

We have already seen the different mechanical characteristics of the ProTaper and the ProFile systems.

The ProTaper is made up of six NiTi rotary instruments. Three shaping files (SX, S1, S2) with multiple and progressive taper to shape the coronal third and middle third of the canal. Three finishing files (F1, F2, F3) with respective tip diameters of 0.20, 0.25 and 0.30 mm to shape the apical third and link it up to the previously shaped coronal and middle third of the canal (Fig. 18.22).

The Pro System GT (section U File) is made up of 12 instruments with tip diameters of 0.20, 0.30 and 0.40 mm available in .04, .06, .08 and .10 taper. The maximum blade diameter is 1mm and this determines a different length for the working part of each instrument (Fig. 18.23).[16]

As we have previously seen, the characteristics of the ProTaper section make these instruments particularly strong, while the characteristics of the U File section of the Pro System GT make these instruments particularly compliant.

In complex anatomies with accentuated curves, consequently a correct operative sequence could be to use the Pro System GT instead of the ProTaper finishing to make use of its compliance in the shaping of the apical third, in harmony with the diameter of the apical foramen and using a taper indicated by the original anatomy (Fig. 18.24).

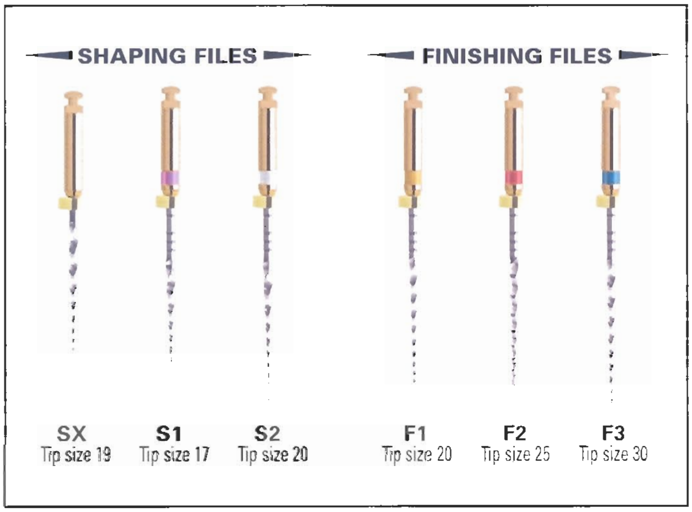


Fig. 18.22. ProTaper System.

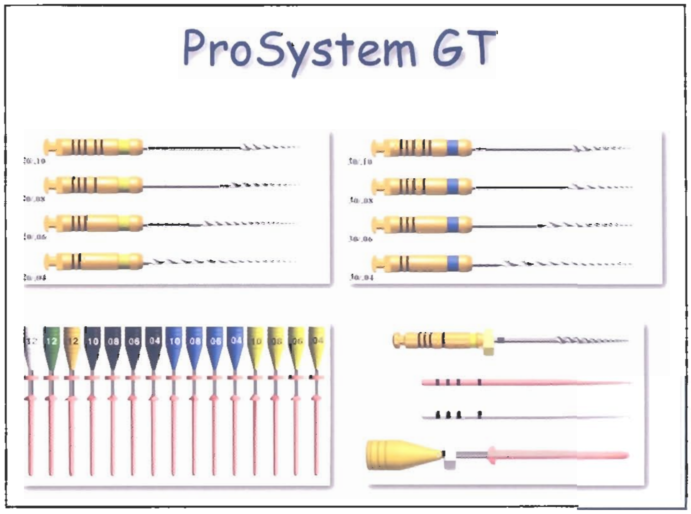
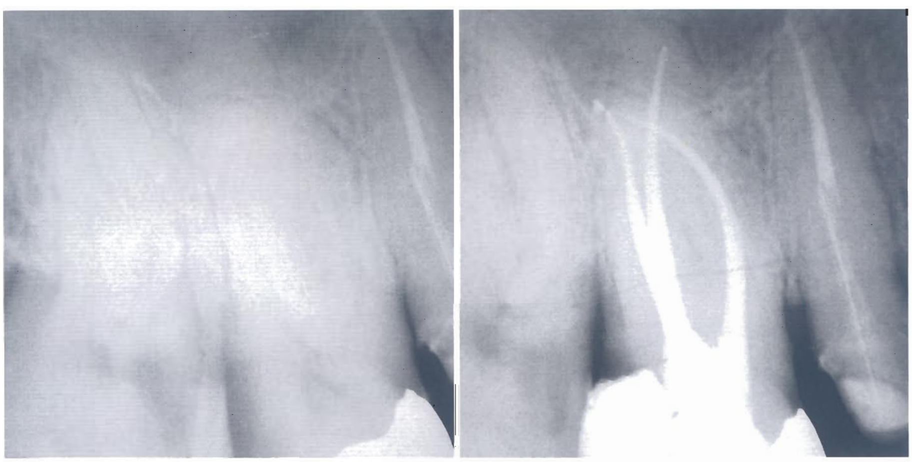


Fig. 18.23. ProSystem GT.



A

B

Fig. 18.24. Clinical cases of teeth with curved canals. ProTaper S1 and S2 were used to shape the coronal third of the canal and the instruments of the ProSystem GT Series to shape the apical one third. **A**. Preoperative radiograph of the upper right first molar. **B**. Postoperative radiograph (E. Berutti) (continued).

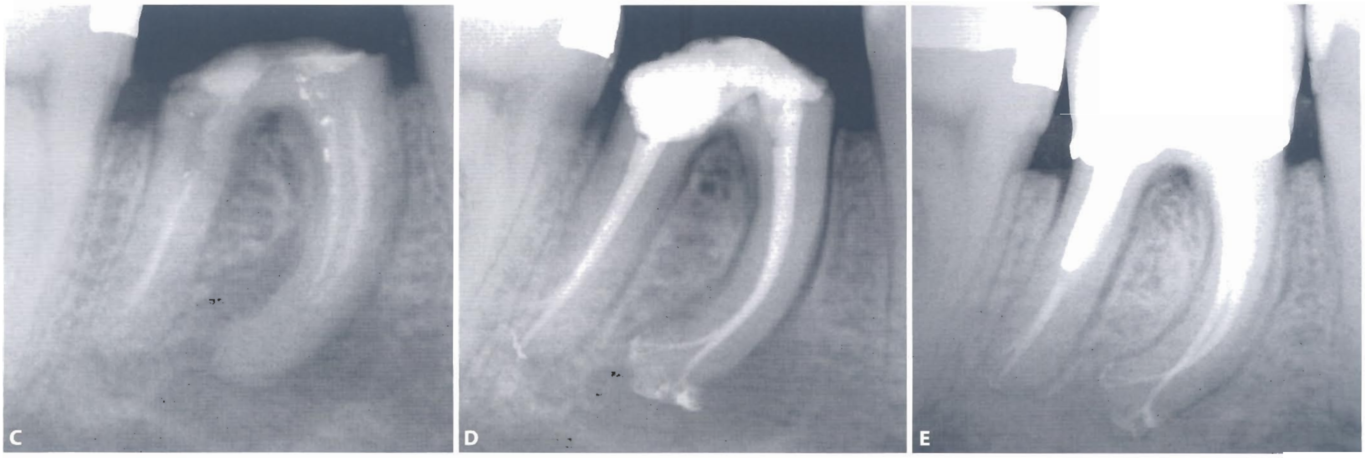


Fig. 18.24. (Continued) **C**. Preoperative radiograph of the lower right first molar. **D**. Postoperative radiograph. **E**. Follow up radiograph at six months (G. Cantatore).

ENDODONTIC MOTORS

Characteristics

As we have previously seen, the characteristics of the NiTi alloy depend on its strongly non linear behaviour. The most performatory phase for the work of the NiTi rotary instrument is the transformation phase, where one sees the superelastic characteristic and the increase in strain without a corresponding proportional increase in stress (Fig. 18.5).

To avoid an excessive and dangerous damage due to cyclic stresses in the NiTi rotary instrument, the alloy should work within this security phase.

The stress which the NiTi alloy absorbs, which is responsible for the phase variations, should be large enough to maintain it in the transformation phase.

The stress to which a NiTi rotary instrument is subjected to is completely different to the stress that a hand instrument is subjected to.

The NiTi rotary instrument in continuous rotation within a canal is subjected to bending stresses, due exclusively to the original canal anatomy and to torsional stresses, that vary as a function of the effort required to cut the dentine. A dedicated motor with which one can operate to maintain the stresses of the NiTi alloy constant is therefore decisive.

The first devices utilized were air driven. They were mounted on dental units replacing the turbines. However, they were soon abandoned because the variations in the air pressure caused the instrument to have dangerous variations of rotational speed.[79,92] Then we had electric motors dedicated to NiTi rotary instruments, able to maintain a perfectly constant rotational instrument speed. In order to do this, the torque utilized was quite high. This sometimes brought about such high stresses that breakages of the rotary NiTi instruments occurred inside the canal.

To avoid fractures as much as possible, in recent years highly soffisticated endodontic motors have been introduced on the market, with which it it possible to control the speed as well as the maximum torque (Figs. 18.25, 18.26).

To keep the speed constant, the torque varies continuously depending on the cutting difficulty and the instruments progression. Each instrument however, has a maximum torque security limit which should not be exceeded. Hence the importance of being able to regulate the maximum utilizable torque that can be reached for that instrument (type, size) for specific work conditions (original anatomy, dentine hardness).

These latest generation endodontic motors are made up of a control system that drives the electric motor which has a contra-angle reduction handpiece attached to its shaft. (ATR Tecnika contra-angle 1:16, Asceptico contra-angle 1:8).

The control system allows one to set the rotational speed and the maximum utilizable torque best indicated for each individual instrument and for each specific working condition. This data can be memorized and therefore successively re-used. The control system is able to store a large amount of data, thereby allowing the operator to utilize many different NiTi rotary instrument systems.

As we have said these endodontic motors allow one to set the desired maximum utilizable torque. When

A

B

Fig. 18.25. **A**. Endodontic motor Tecnika Vision (ATR and Sirona Company, Italy). **B**. Endodontic motor DTC (Aseptico, USA).

A

B

Fig. 18.26. **A**. Endodontic motor DentaPort (J. Morita Corp., Japan). **B**. Endodontic motor X-Smart (Dentsply Maillefer, Ballaigues, Switzerland).

the instrument, working in the canal, reaches this value, the operator can choose to utilize a signalling system provided for in the motor: acoustic signal and /or inversion of the rotational direction (autoreverse).

When the maximum torque value preset by the operator has been reached the motor will reverse the rotation and the instrument turning anti-clockwise, will automatically exit the canal.

The most evolved endodontic motors (ATR Tecnika) pride themselves on having a soffisticated autoreverse control system which is primed in a fraction of a second, so as to prevent further stress fatigue damage in the NiTi rotary instrument, once the preset maximum torque value has been reached.

Formulation

The correct formulation of the endodontic motors is indispensable to guarantee the efficient use of the NiTi rotary instruments. Efficiency means maximum durability of the instrument without risk of fracture. We have previously seen how all endodontic motors available today are torque controlled. On the basis of the NiTi rotary instrument characteristics and on the basis of the original anatomy characteristics, the operator will have to set the rotational speed and the maximum utilizable torque, that is the highest torque value that the instrument can reach before the endodontic motor automatically triggers the autoreverse.

Until now we have spoken of rotational speed and maximum utilizable torque that the instrument can withstand without risks. It is evident how the two parameters are closely linked.

If the speed increases then as a consequence the torque will increase so as to maintain the rotational speed increase of the instrument constant.[9,91] Proportionally however, the risks of fracturing the instrument inside the root canal also increases.[5,92]

If the rotational speed is too low, the instrument will tend to come to a halt within the canal, its work will be discontinuous, with the risk of an excessive fatigue damage due to stresses especially in the successive anti-clockwise rotation which is necessary to disengage the instrument.[35]

The correct balance is therefore needed between these two values to obtain the maximum efficiency without risks.

The introduction of an endodontic motor that allows the regulation of the utilizable maximum torque value that the NiTi rotary instrument will be able to reach during its work, has the aim of preventing the fracture of the instrument inside the canal. Consequently the utilizable maximum torque value that the operator sets on the endodontic motor will have to be lower than the torque value able to produce plastic strain and then fracture of the NiTi rotary instrument at that speed of rotation.[10,91,92]

The maximum utilizable torque value must however not be too low because in this case the cutting efficiency of the instrument would decrease excessively and the progression of the instrument in the canal would be difficult. Consequently the operator would tend to push on the handpiece of the endodontic motor to aid the progression of the instrument in the canal with a high risk of fracturing it.[10,91,92] These two parameters, speed and torque, are specific for each system of NiTi rotary instruments and often for each instrument within the system.

These parameters are determined by the mechanical characteristics and size of the instruments.

We have previously seen how the section of the mechanical instrument determines its properties. For example the ProTaper section (triangular convex) proved to be very resistant to torsional and bending stresses. It follows that it will be able to withstand elevated stress in terms of rotational speed and utilizable maximum torque.

The ProFile (U File) section proved to be more flexible by comparison to the ProTaper section because the ProFile section, for equal diameter, has a 30% inferior mass compared with the ProTaper section and therefore proves to be more compliant. This lower mass means however, also a lesser strength to the stresses and consequently to the rotational speed values and utilizable maximum torque that the instrument is able to withstand without risks.

Even the design of the blades and therefore the cutting capacity are important.

The more the blades are active, (ProTaper System; Dentsply/Maillefer) and therefore able to cut the dentine, the more the utilizable maximum torque value can rise (Fig. 18.18). This because the cutting efficiency is translated into ease of progression in the canal by the instrument and generically because cutting efficiency is determined by a reduced surface contact between blade and canal walls.

It follows that the torsional stresses during the cutting of the dentine are reduced. The NiTi rotary instrument in this way be able to work with a high maximum torque, without fatigue damage increase. On the contrary, if the blades have a reduced cutting capacity (ProFile System, Dentsply/Maillefer) the stresses which are generated during the working of the instrument are increased (Fig. 18.18). These are principally determined by the friction that occurs between the blades and the canal walls. The torque required to induce the instrument to advance in the canal will be high because the removal of the dentine will be less effective with the risk of an excessive fatigue damage due to cyclic stresses.[89] These instruments must therefore be used cautiously and with low maximum torque values, to prevent an excessive accummulation of stress on the part of the instrument.

A further characteristic of the NiTi instrument is its size and calibre.

If the instrument size increases then its resistance to torsional stress also increases.[10,66] On the contrary instruments with small apical portions will not be able to withstand elevated torsional stresses (Fig. 18.27).[10,89,92] This consideration is only valid for the NiTi rotary instruments with constant taper (ProFile, System GT, Hero, K3 etc). The NiTi rotary instruments with multiple taper (ProTaper), having in the shape of the instrument itself the crown-down technique and therefore each one working in a specific sector of the canal, are all utilized at the same rotational speed and with a high utilizable maximum torque. (300 rev. per minute, 100% torque value in Tecnika ATR). Such a high torque enhances the marked cutting ability of the ProTaper, thereby considerably reducing the working time.

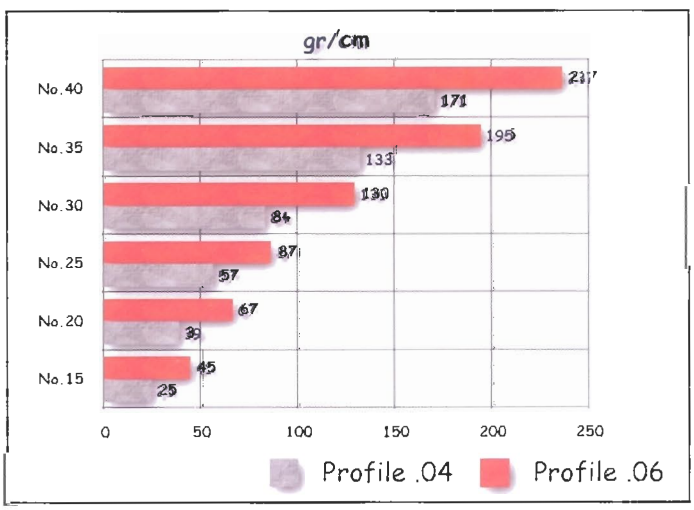


Fig. 18.27. Diagram illustrating how the torsional resistance increases with the increase in taper. Comparison between the ProFile .04 and the ProFile .06.

LIFE OF THE NITI ROTARY INSTRUMENT

After having examined the technical characteristics and the operative sequence, the obligatory questions are: "how long do these instruments last? how many canals are we able to shape?"

We have previously seen how the stress accummulated by the instrument during its work is dependent on the tip size, on the taper, on the canal width and on the manual pressure exerted on the handpiece of the endodontic motor, by the operator.[66]

The life of the NiTi rotary instrument is directly proportional to the stress which it accummulates during its work within the canal.[31,88,95]

Pruett et al.[58] have demonstrated that the life of the NiTi rotary instruments are strictly related to the number of cycles performed by the instruments within the canal.

Naturally, life is different for each type of instrument, but it is extremely constant for instruments having the same characteristics.

We can compare the NiTi rotary instrument with a car having a full tank of fuel. The fuel can be used to go uphill, downhill, on a flat terrain, on a motorway or to journey on a mixed terrain. Naturally the consumption and consequently the distance covered will be different.

An important role is also played by the driver: if he uses the accelerator sparingly the comsumption will most likely be reduced and it follows that the distance covered will be greater.

The NiTi rotary instrument, created with its tank full of fuel (life), will be used to shape simple endodontic anatomies, complex ones, or a combination of these.

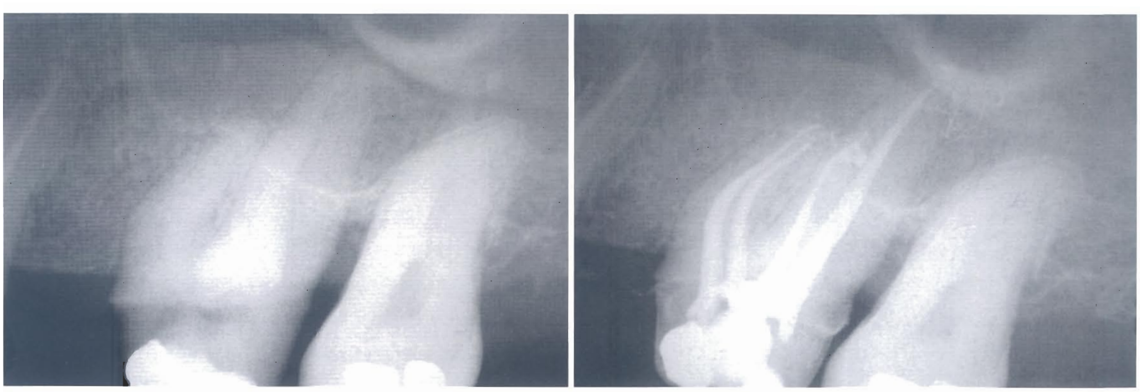
Let us now examine the criteria that will influence the life of the instrument:

1) Original canal anatomy
2) Mechanical characteristics of the NiTi rotary instruments
3) Rotational speed and maximum torque values when using NiTi rotary instruments
4) Characteristics of the work carried out by the NiTi rotary instruments
5) Operator ability

1. Original anatomy of the canal

The original anatomy of the canal is certainly the factor that most conditions the life span of the NiTi rotary instrument.[66]

We have previously seen how strain is to a large extent determined by the bending stress that the NiTi rotary instrument experiences during preparation of the curvature of the root canal.[71] Some Authors[32,58] do not consider rotational speed significant as a factor favouring the fracture of NiTi rotary instruments. On the contrary various studies[27,29,51] have shown that instrument rotational speed in curved canals has a notable influence on the life of the NiTi rotary instruments. It is intuitive that increasing the speed also increases the contact with the canal wall and therefore the amount of debris between the instrument blades and the wall.[29,67] But the determining factor always seems to be the number of rotations the instrument makes in the curve. Yared[88] has shown that the longevity of the instrument is strictly correlated to the number of rotations it makes inside the canal. The more complex the anatomy is, the more wear there is in terms of increased fatigue damage and therefore the life of the instrument is reduced. Therefore the curve radius and angle of the canal which the instrument has to shape is determinant in the cyclic fatigue of the instrument (Figs. 18.28, 18.29).[12,51,58,95]



A B

Fig. 18.28. Clinical cases of teeth with canals having moderate curvatures. **A.** Preoperative radiograph of the upper left first molar. **B.** Postoperative radiograph (E. Berutti) (continued).

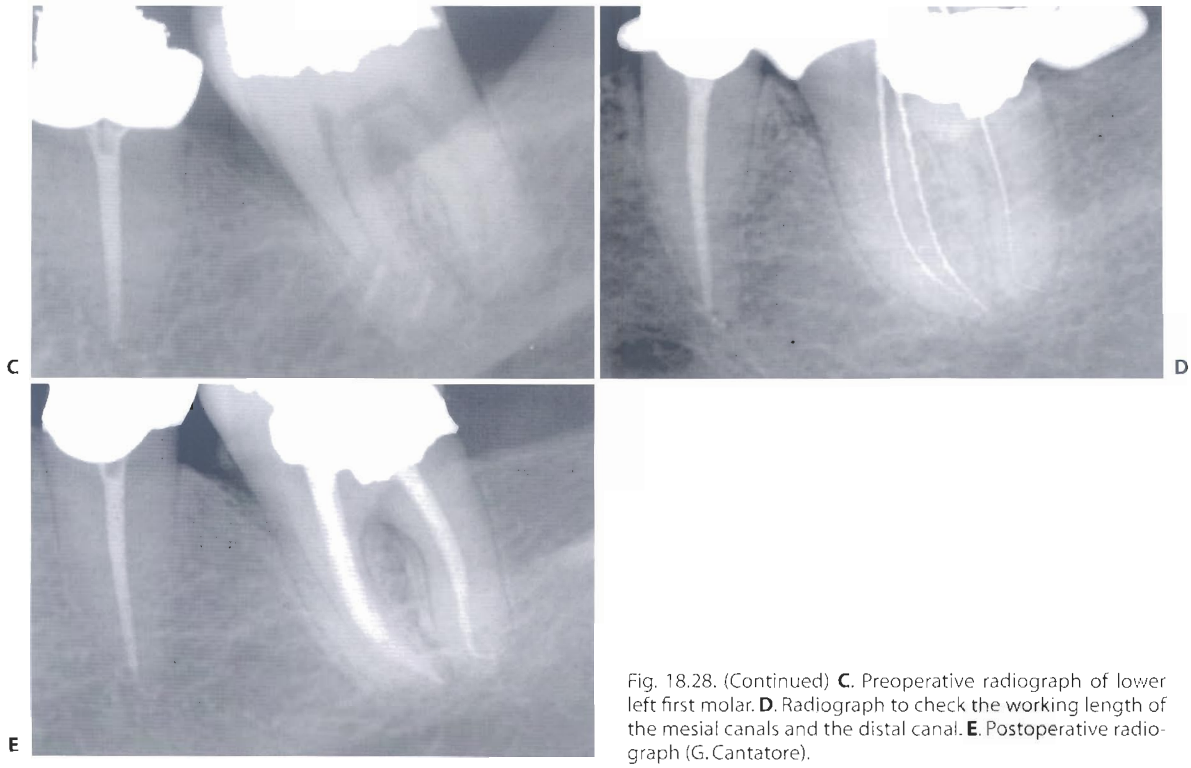


Fig. 18.28. (Continued) **C**. Preoperative radiograph of lower left first molar. **D**. Radiograph to check the working length of the mesial canals and the distal canal. **E**. Postoperative radiograph (G. Cantatore).

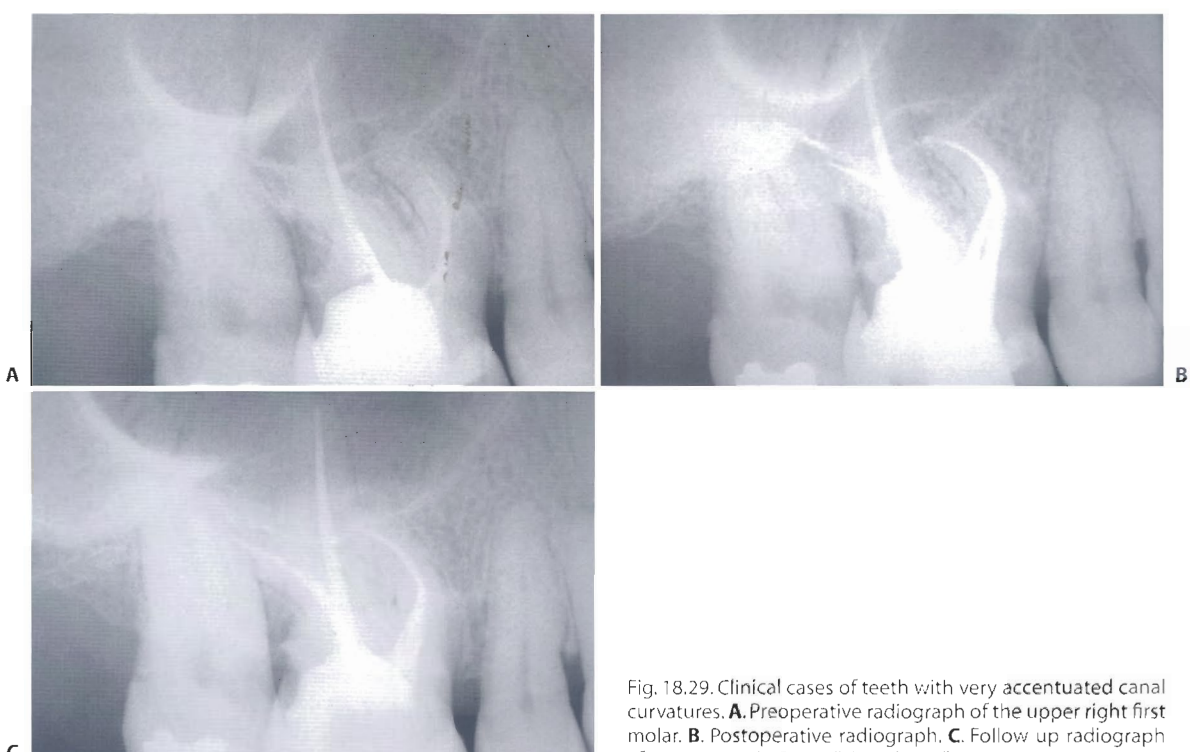
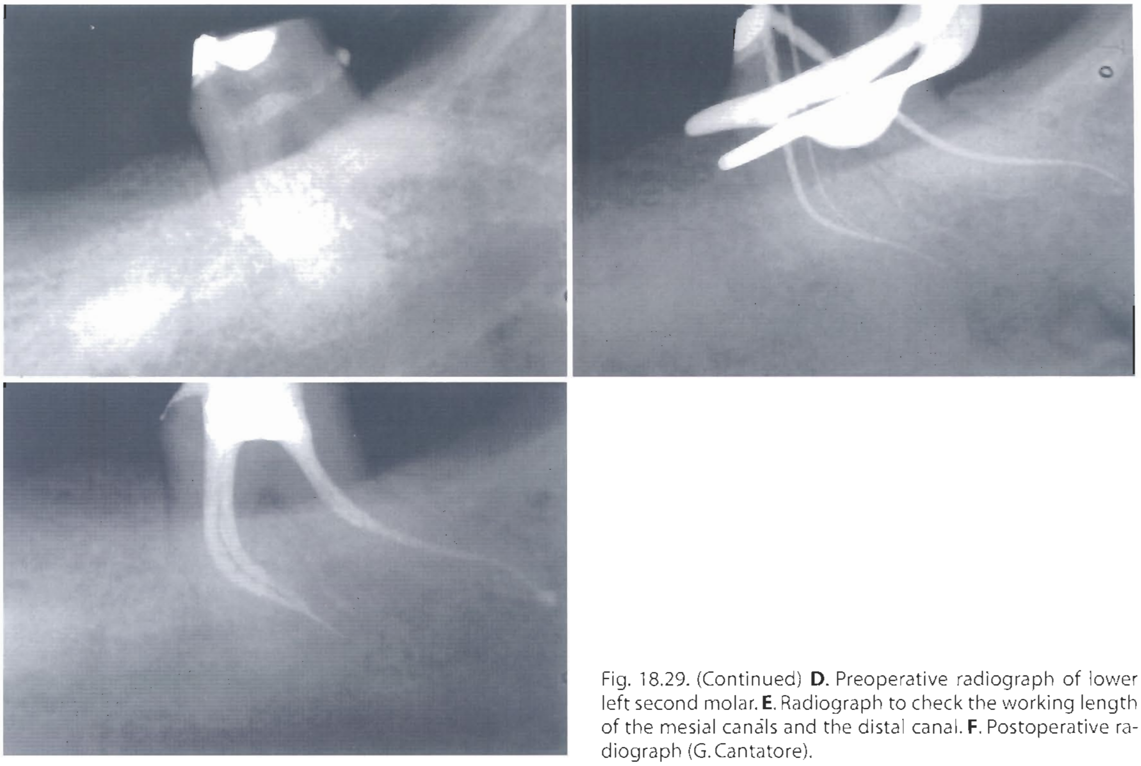


Fig. 18.29. Clinical cases of teeth with very accentuated canal curvatures. **A**. Preoperative radiograph of the upper right first molar. **B**. Postoperative radiograph. **C**. Follow up radiograph after one year (E. Berutti) (continued).

D

E



F

Fig. 18.29. (Continued) **D.** Preoperative radiograph of lower left second molar. **E.** Radiograph to check the working length of the mesial canals and the distal canal. **F.** Postoperative radiograph (G. Cantatore).

The original anatomy of the canal however, with its curvatures is not the only factor in reducing the life of the instrument, since the size of the canal and the characteristics of the dentine are also decisive.

The cutting ability of the NiTi instrument tip is not generically very efficient. This causes an immediate increase in the torsional stress that the instrument accummulates when it must advance in those canal sections of equal or inferior diameter to its tip diameter.[30]

This is easily detectable by the immediate increase of the torque values that the engine must supply to overcome the obstacle. This fact is easily detectable for example on the Tecnika ATR motor display, where one can see the torque variations on a digital and acoustic indicator. To this end we must recall the importance of a manual preshaping which prevents the engagement of the NiTi rotary instrument tip against the canal walls, in this way drastically reducing the torsional stress.[1,12,45,57,65] Even bending stress is partially reduced after a manual preshaping. The enlargement of a root canal will produce gentler curves which are therefore less demanding. The life of the instrument will thus be considerably increased. Blum et al.[16] have shown that the coronal interferences are responsible for high levels of stress that the NiTi rotary instrument accummulates during its work.

Dentine hardness also affects the accummulation of torsional stress. Pulp characteristics and consequently those of the dentine change as time passes due to normal ageing or to pathological events such a, pulpal inflamation and trauma. The result of these events frequently results in a dentine hypermineralization and in a considerable reduction of the endodontic space.

Harder dentine requires a proportional increase in the torque value needed to cut it. This results in an increase of the torsional stress which reduces the life of the instrument.

Even in these specific clinical conditions a manual pre-flaring and the abundant use of chelators and lubrificants aid the work of NiTi rotary instruments.

2. Mechanical characteristics of the selected instruments

Theoretically to optimize the use of NiTi rotary instruments and to avoid problems (fractures) the instrument should be subjected to low levels of stress. We have previously seen at great length how the shape of the instrument determines the mechanical properties. The more the section is able to withstand high levels of torsional stress the more it is resistant. The more the section has a low bending moment, the more compliant it is and therefore able to respect the original canal anatomy.[58,81]

The capability of an instrument to resist the stress and at the same moment to respect the curvature of the canal is therefore a compromise between the torsional and bending characteristics of its section.[22,38]

If we want an extremely compliant instrument we must accept that its working life will not be as long as that of an instrument which is more resistant but less flexible. Strength and compliance are correlated to the mass of the section: the more the mass is reduced, the more the instrument will be compliant and consequently less resistant and vice versa.

Instruments with the same characteristics have different mechanical behaviours in relation to their size. If the instrument has a small calibre, it has reduced strength capabilities to torsional stress, if on the contrary it is big, it is more prone to fracture because of bending stress (Figs. 18.30, 18.31).[58,67] This in part explains the unexpected fractures when we work with large instruments in the final phases of the shaping. We must therefore think of small instruments as having a low strength to torsional stress and of large instruments as having a low strength to bending stress.

The operator will be able to prevent the fracture of the instruments within the canal by a having a precise treatment plan that provides for the correct choice of instruments and operative sequence suited for the specific canal anatomy that has to be shaped. If for example one has to shape a canal that has an extreme curvature , one should use an instument with reduced taper (.06, .04) because as we said before they more resistant to cyclic fatigue (Fig. 18.32). Instead if one has to shape a canal that is extremely narrow and calcified it would be necessary to firstly carry out an adequate manual preshaping to to reduce the torsional stress (Fig. 18.33). Finally to prevent possible fractures, all the NiTi rotary instruments must be accurately checked, using magnification, before and after every use.

The instrument which presents the slightest sign of plastic strain (increase or decrease of the spiral gaps) should be eliminated immediately (Fig. 18.34).[30,80]

The NiTi rotary instruments differ from the stainless steel instruments in that the first signs of fatigue are not always visible.[49,58] If a fracture has occurred because of torsion in some cases signs of plastic strain are visible just above the fracture point.[67] If instead the fracture has occurred because of fatigue(flexion)the signs of instrument deterioration are not evident.[67] If the canal anatomy is extremely complex (severe curvatures, calcified canal) the NiTi rotary instruments must be considered single use only.[1]

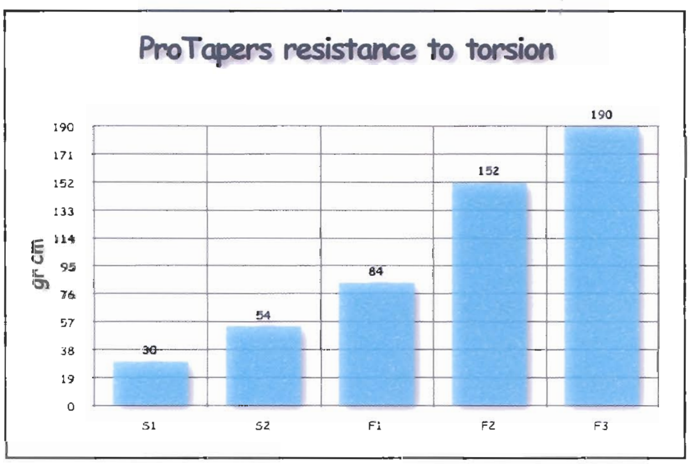


Fig. 18.30. Diagram illustrating how the strength to torsion increases with the increase in the diameter of the instrument. Comparison between the instruments of the ProTaper Series.

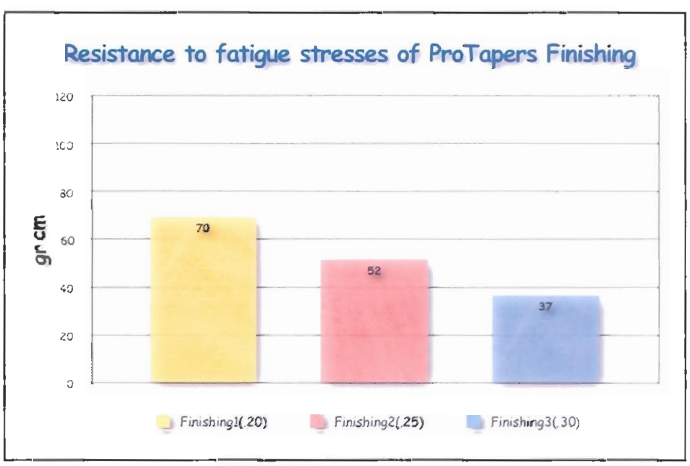


Fig. 18.31. Diagram illustrating how the resistance to bending increases with the reduction of the cross-section diameter of the instrument. Comparison between the Finishing instruments of the ProTaper Series.

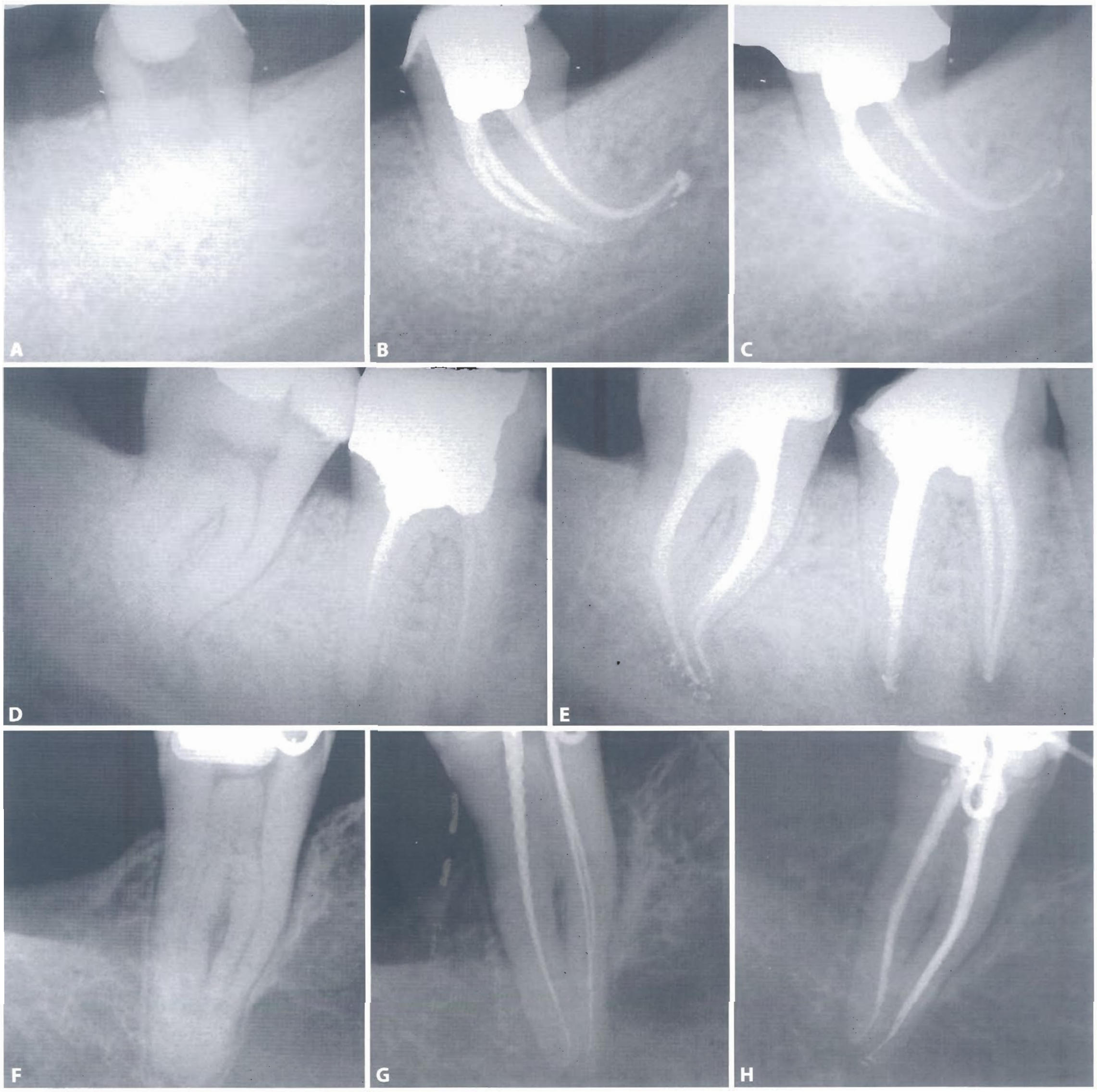


Fig. 18.32. Clinical cases of teeth with very accentuated canal curvatures. In these cases it is important to use NiTi rotary instruments with low taper to prevent fracture due to cyclical fatigue. **A**. Preoperative radiograph of a lower left third molar. **B**. Postoperative radiograph. **C**. Follow up radiograph after one year (E. Berutti). **D**. Preoperative radiograph of a lower right second molar. **E**. Postoperative radiograph (E. Berutti). **F**. Preoperative radiograph of a lower right second molar. **G**. Radiograph to check the working length of the mesial canals and the distal canal. **H**. Postoperative radiograph (G. Cantatore).

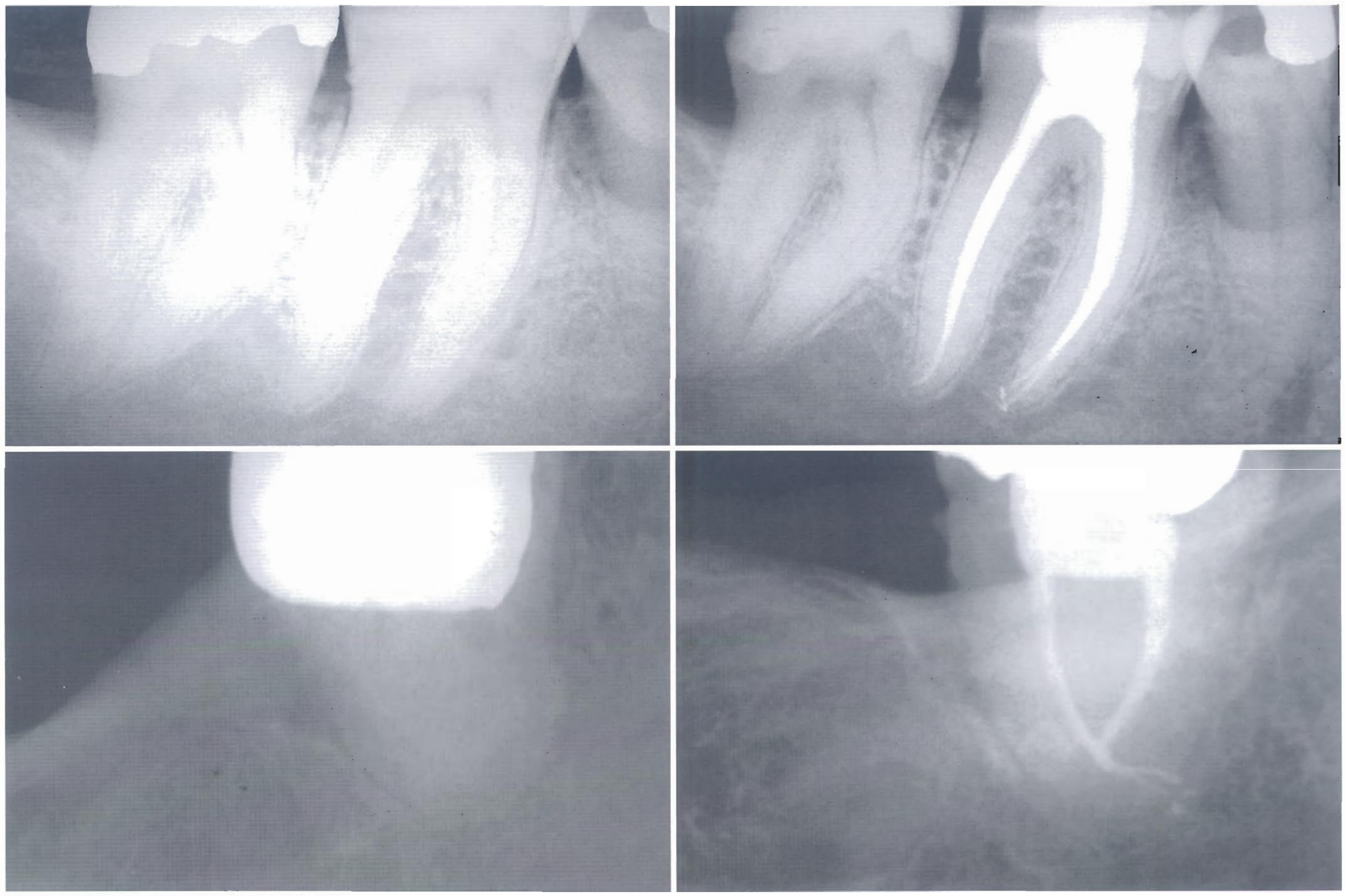


Fig. 18.33. Clinical cases of teeth with calcified canals. In these cases it is very important to have an adequate manual preflaring to reduce torsional stresses. **A**. Preoperative radiograph of the lower right first molar. **B**. Post operative radiograph (E. Berutti). **C**. Preoperative radiograph of the lower left third molar. **D**. Postoperative radiograph (G. Cantatore).

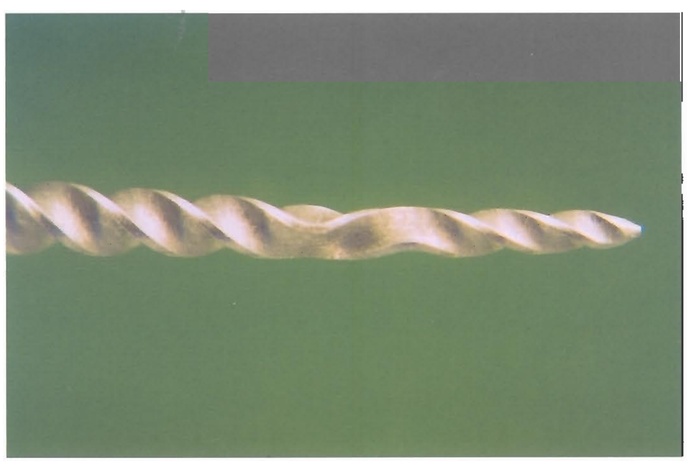


Fig. 18.34. ProFile .06 with visible plastic deformation.

3. Rotational speed and maximum torque values for NiTi rotary instruments

We have seen before how important the balance is between the rotational speed, which should be constant and the maximum torque used, which should be less than the torque value necessary to cause plastic strain and subsequently fracture of theNiTi rotary instrument.[40,91,92]

It is therefore essential to use an electric motor that allows one to set the rotational speed and maximum torque value to be used according to the recommendation of the manufacturer for the particular rotary NiTi rotary instruments.

4. Characteristics of the work carried out

The characteristics of the work carried out by the NiTi rotary instrument have a very important role.[23] There are two factors which influence the work of the instrument:

- the section of the working part directly involved with the cutting
- the depth at which the instrument carries out its work within the canal.

The smaller the working portion of the instrument directly involved with cutting the dentine, the lower the torsional stresses. This is carried out with the instruments using the crown-down technique (Figs. 18.10, 18.11).

The more the instruments work deeply into the canal, the more their life is reduced, whether they work in areas where the canal is narrow and often with accentuated curvatures, or because the instrument works with the smallest portion of its working part. To this end we must remember the importance of not remaining stationary with the NiTi rotary instrument within the canal. Once the maximum working depth for that instrument is reached, one must remove it immediately. This allows a homogenous distribution of bending and torsional stress in the entire working area of the instrument. In this way dangerous areas due to damage will not be created.

At this point it is important to make a comment: within a series of NiTi rotary instruments each one has a different life in relation to its size and to the characteristics of the work carried out within the canal. This is particularly evident for the instruments of the ProTaper System (Dentsply/Maillefer) instruments with multiple taper along their working part.

Berutti et al.[7] have verified how many endodontic simulators the instruments of the ProTaper System S1, S2, F1, F2 utilized in sequence were able to shape before breaking.

These were the results:

S1: 59 endodontic simulators before breaking. The multiple taper of the S1 limits the work to only the coronal one third of the canal.

S2: 48 endodontic simulators before breaking. The multiple taper of the S2 limits the work to the middle one third of the canal. The first observation is that the life of these two instruments under these conditions is very long. However, they work in the areas of the canal, closest to the crown with the largest and strongest sections of their working parts.

F1: 23 endodontic simulators before breaking.

F2: 11 endodontic simulators before breaking.

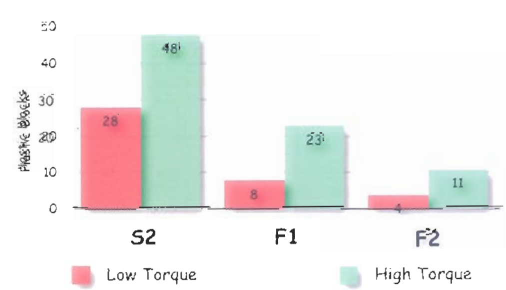
These two instruments shape the apical one third of the canal. They are subjected to very high bending and torsional stresses in the smallest and consequently weakest section of their working part (apical 3 mm). A further important fact that emerged from this study is that if the instruments of the ProTaper System work with a lower torque, they have a considerably shorted life.

The following results were obtained using the Tecnika ATR endodontic motor (Fig. 18.35):

S2: torque 20%, speed 300 rpm = 28 simulators before breaking.

S2: torque 80%, speed 300 rpm = 48 simulators before breaking.

F1: torque 28%, speed 300 rpm = 8 simulators before breaking.



Berutti E, Negro AR, Lendini M, Pasqualini D:
Influence of manual pre-flaring and torque on the breakage rate of ProTaper rotary instruments.
J Endod 2004; 30: 228-230.

Fig. 18.35. Diagram illustrating how torque influences the longevity of ProTaper S2, F1, F2 NiTi rotary instruments.

F1: torque 100%, speed 300 rpm = 23 simulators before breaking.
F2: torque 40%, speed 300 rpm = 4 simulators before breaking
F2: torque 100%, speed 300 rpm = 11 simulators before breaking.

This notable and constant difference in the life of the tested ProTaper System instruments resulted from the frequent insertion of the autoreverse of the endodontic motor when the utilizable torque was low. Instead when the instruments worked with a high torque, the autoreverse was never switched on. The autoreverse is not harmful, infact it is an excellent security system, especially for the instruments that have to work with a low utilizable maximum torque (ProFile, System GT etc).

It is however a system that in inverting the clockwise rotation of the instrument when it reached utilizable maximum torque value involves a certain effort (Fig. 18.36). This means stresses that the instrument stores and consequently a reduction of its life.

If possible, the operator should avoid all superfluous work for the NiTi rotary instrument. If the instruments require a low usable torque, it is sufficient to allow oneself to be guided by the digital and acoustic indicator of the endodontic motor and to withdraw the instrument just before the autoreverse sets in. In this way we will avoid superfluous stress, limiting the life of the endodontic instrument to only the cutting of the dentine in harmony with the complexity of the endodontic anatomy.

If one analyses the diagrams that summarise the number of simulators shaped using the ProTaper S1, S2, F1, F2 in the study done by Berutti et al.[7] it becomes evident that there is a continuous reduction in the life of the ProTaper rotary instruments from S1 to F2 (Fig. 18.37). This is true although only for canals shaped using endodontic simulators.

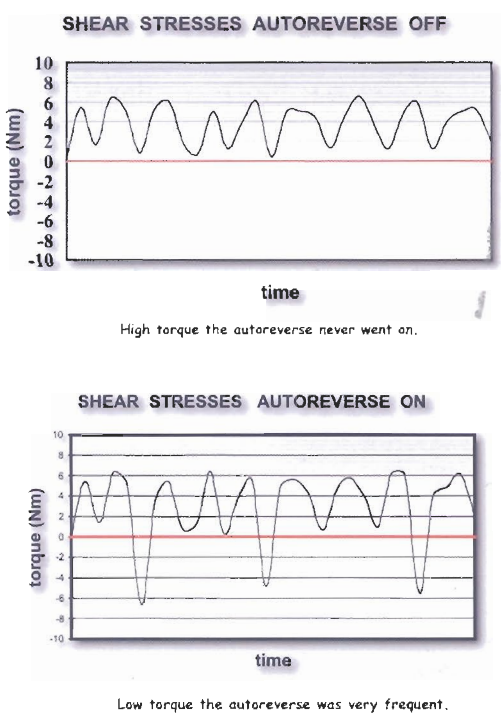


Fig. 18.36. Registration of the torque variation during use of a ProTaper F2 to reach the canal terminus in a plastic block. **A.** High torque: one notes the regular variation of torque and their low intensity. **B.** Low torque: one notes the enormous variation of the torque during activation of the autoreverse by the endodontic motor. The instrument carries out twice the work load when the autoreverse is activated.

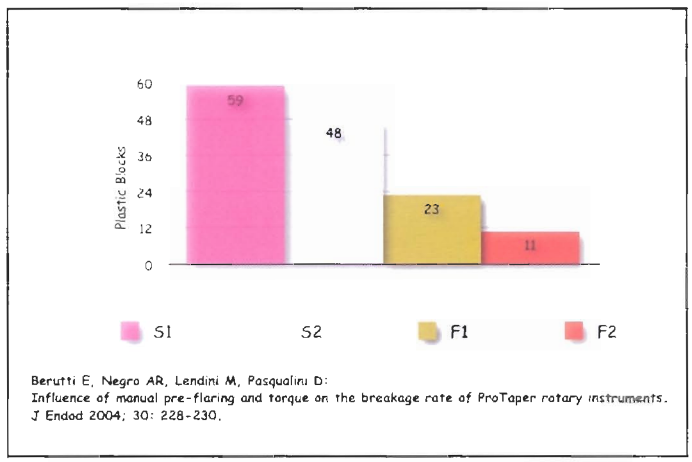


Fig. 18.37. Diagram illustrating the number of plastic blocks shaped by the ProTaper S1, S2, F1, F2 NiTi rotary instruments before fracturing.

The endodontic simulators do not crrespond to the clinical reality for two reasons:
1) the simulator canals are all the same which explains the propotionality of the data obtained
2) the simulators are made from plastic which has completely different characteristics to that of root canal dentin.

To obtain data closer to reality one must therefore simulate the clinical situation as closely as possible by using root canals of human teeth. In this regard, the successive work done by Berutti et al.[8] done on 410 extracted permanent human teeth with a total of 677 canals is particularly interesting. In this study the ProTaper S2 proved to have the longest life of the series while the F2 had the shortest life.

5. Operator ability

It has been demonstrated that the experience of the operator is decisive in preventing the fracture of the NiTi rotary instruments inside the canal.[40,48,90-92]

The inexperienced operator probably exercises an excessive apical pressure during the use of the NiTi rotary instruments.[48,54] This brings about excessive friction of the instrument blades against the canal walls. The NiTi rotary instrument is in this way immediately subjected to very high torque levels necessary to maintain the speed constant.[79] The result is either an excessive accumulation of fatigue damage due to torsional stresses or even a plastic strain and then the instrument fractures. Sattapan et al.[67] have demonstrated that torsional fractures are more frequent (55,7%) compared with fractures from bending stress (44,3%) and they are brought about by the operator who excercises an excessive apical pressure during the use of the NiTi rotary instruments. Blum et al.[10] have shown that the levels of maximum stress are generated during the penetration phase of the instrument in the canal rather than during the retraction phase.

Very important in fracture prevention is also the method of use.[11,74] The inexperienced operator also tends to hesitate with the instrument in rotation inside the canal for too long. Mesgouez et al.[52] studied the relationship that exists between the experience of the operator and the time required to shape the canals. They used the NiTi Profile rotary instruments and endodontic simulators. The results showed that the time required to shape a canal was inversely proportional to the operators experience. Berutti et al.[8] previously carried out a similar study using 410 extracted permanent human teeth with a total of 677 canals. The NiTi rotary instruments used were the ProTaper. The diagram showed in Fig. 18.38 summarises the average time each instrument of the ProTaper series was used to shape a single canal by an experienced operator and by an inexperienced operator. The experienced operator is able to shape more canals because the average working time with each instrument is inferior to that of an inexperienced operator. The inexperienced operator is afraid of advancing and withdrawing the instrument in the canal. Therefore more time is required. This causes an unecessary stress overload which the instrument accumulated during the excessive amount of time spent rotating in the canals. If it is true that the operator must not apply excessive manual pressure on the handpiece,[79] then it is also true that the instruments must complete their work inside the canal in the least amount of time possible.[8,47,52,58,81] As we have emphasised previously the movement must be continuous and fluid on entering the canal and also on withdrawal.

This brings about a useless overload of stress that the instrument accummulates. If the operator then keeps the rotating instrument stationary while in a curve of the canal, a damaged area is created that corresponds to the section with the lowest curvature radius, where the bending stress are at a maximum. Sattapan et al.[66] have demonstrated that if the instrument is utilized with a light back and forth movement, the stress which develop in the apical area of the instrument are relatively low even in narrow canals, independantly of instrument size and taper. The expert operator is able to feel the advance of the NiTi rotary instrument in the canal on the handpiece and can therefore guide it with the correct pressure and extract it immediately when it reaches the desired working length.

Some operators have the tendency to incline the endodontic motor handpiece.

In this way a curvature is created of the instrument outside of the canal and an increase in the load on the instrument portion inside the canal. Even in this case there will be an increase in stress and in the risk of fracture of the NiTi rotary instrument.[79]

One must also note how many times accidents happen at the end of the shaping, during final passage with the last instrument.

This is perhaps brought about by a decrease in concentration on the part of the operator, who knowing that he/she is at the end of the work, doesn't keep rigidly to the rules and perhaps exerts excessive pressu-

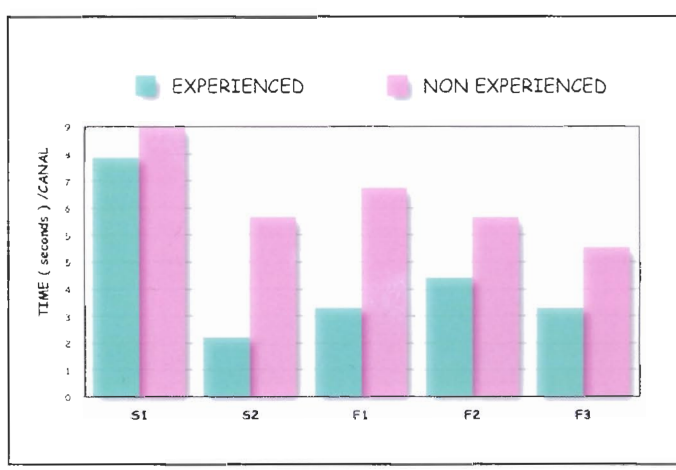


Fig. 18.38. Diagram illustrating the average time of use of each ProTaper S1, S2, F1, F2, F3 NiTi rotary instruments to shape a root canal by a skilled operator (green) and by a not skilled operator (purple).

re on the handpiece to end the treatment rapidly.[19,47,88] Yared et al.[88] recommend that the use of NiTi rotary instruments follows rigid guidelines: the apical pressure that is exerted on the instrument must be very light, and its use inside the canal must last only a few seconds.

During the manual preshaping, the experienced operator will be able to enterpret the difficulties presented by the original canal anatomy. If the original canal anatomy is complex, manual shaping will be more important in reducing the stresses in the NiTi rotary instruments that will follow (Fig. 18.39).

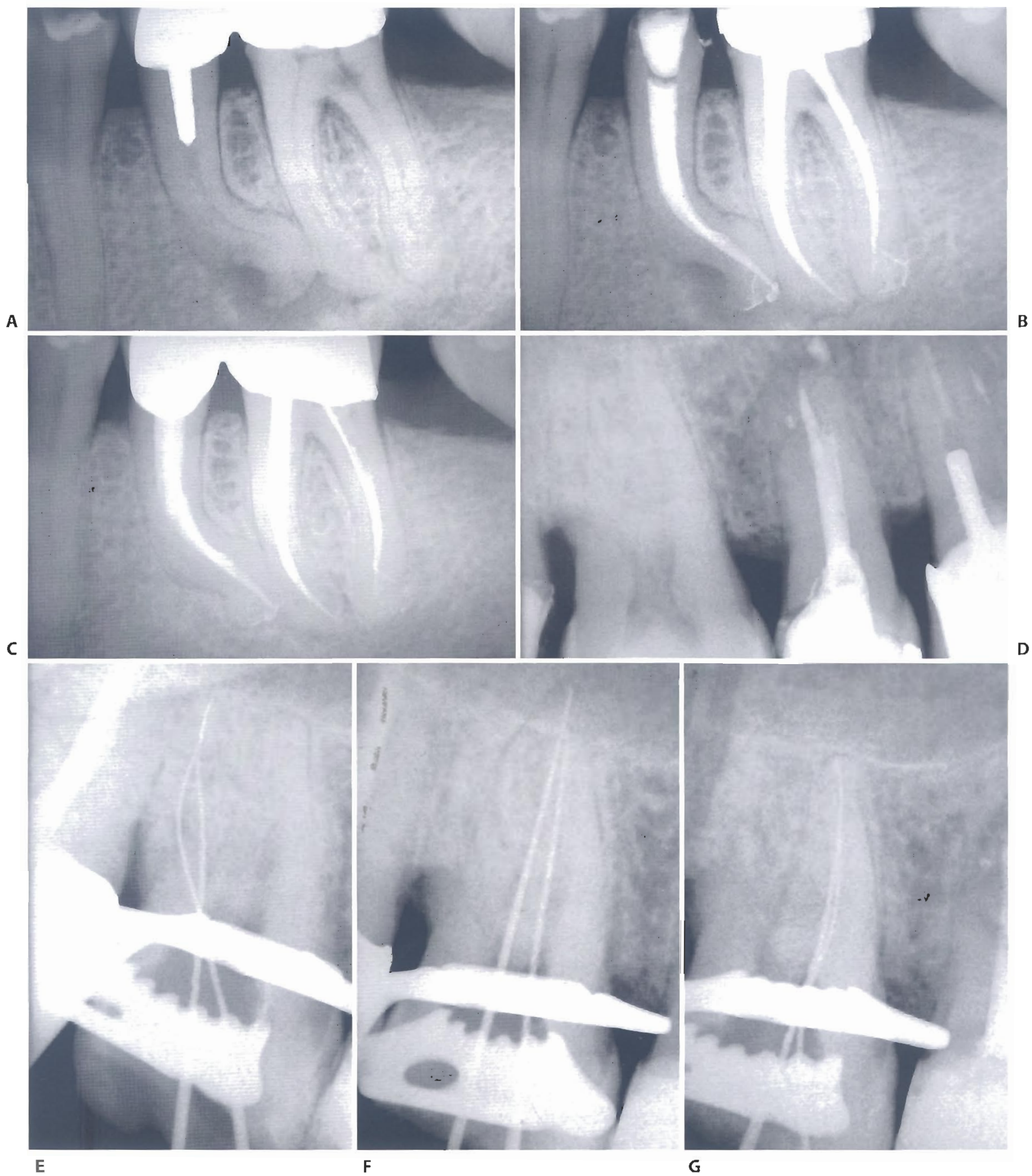


Fig. 18.39. Clinical cases of teeth with canals having a complex original anatomy. In these cases manual preflaring will be more important in order to reduce stresses in the successive NiTi rotary instruments. **A.** Preoperative radiograph of a lower left second premolar. **B.** Postoperative radiograph. **C.** Follow up radiograph after one year (E. Berutti). **D.** Preoperative radiograph of the upper right first molar. **E.** Radiograph to check the working length of the distal canals. **F.** Radiograph to check the working length of the palatal canals. **G.** Radiograph to check working length of mesial canals (continued).

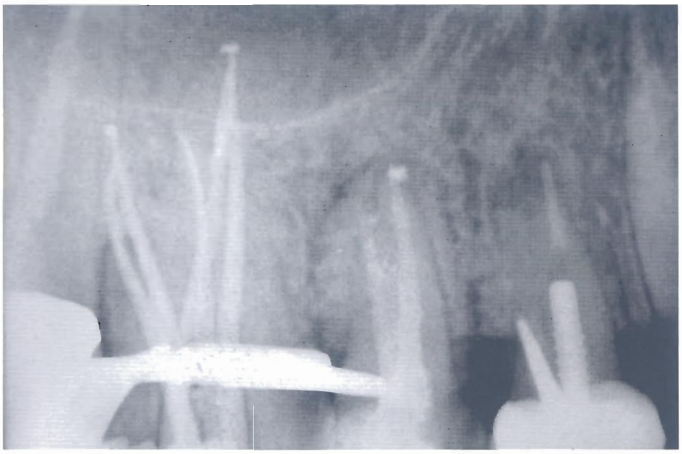


Fig. 18.39. (Continued) **H.** Postoperative radiograph (G. Cantatore).

We must be aware that, as Ruddle taught us "its the original canal anatomy that determines the game plan". The experienced operator will have to carefully check, using a magnification system, each instrument after having used it inside the canal, not only to verify its good working condition, but also to understand the workload it carried out. If a large portion of the working part is full of dentinal debris, the work carried out by the instrument has been significant. If then the portion of the working part concerned with the cutting was the apical part, it means that the instrument has worked in a very narrow canal and that the price for enlarging it was very high in terms of accummulated stresses (Fig. 18.40). The life of that instrument could be at an end.

The working length of the NiTi rotary instruments often does not have to coincide with the working length of the canal. This is especially so when the complexity of the anatomy of the apical third can favour the fracture of the NiTi rotary instruments and / or the incorrect shaping of this important portion of the root canal (Fig. 18.41).

Even the choice of the NiTi rotary instruments and the correct operative sequence will have to be modulated in relation to each specific clinical case.

In this mechanistic age therefore it will always be the operator with his choices and his manual dexterity, that will know how to make the difference.

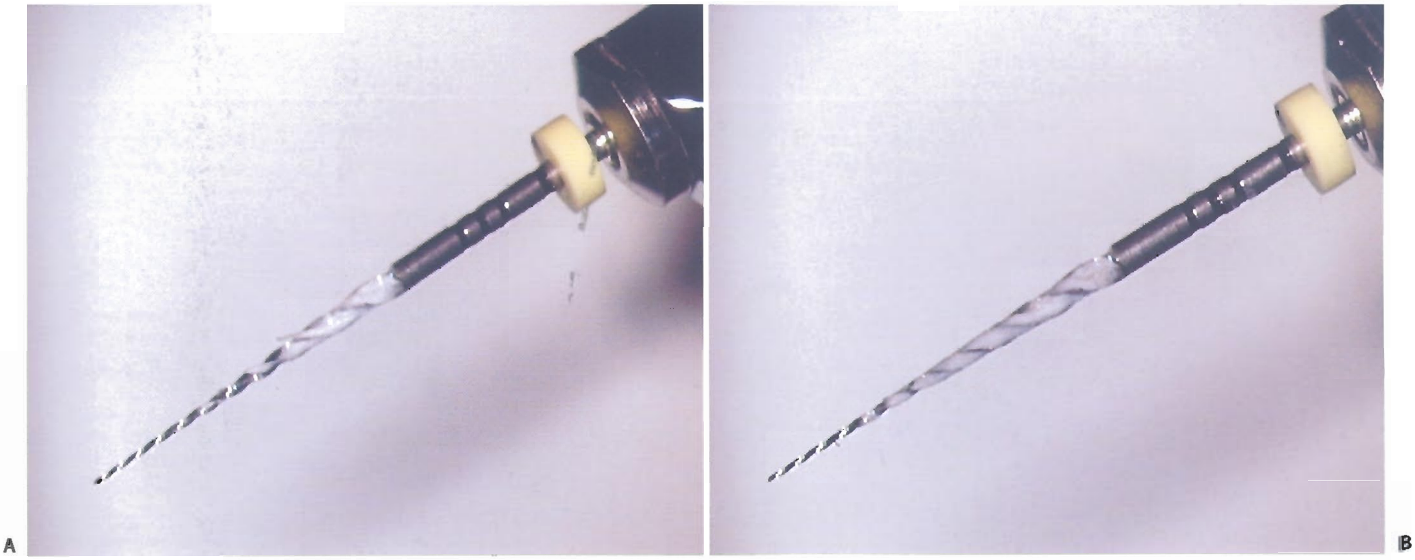


Fig. 18.40. **A.** Protaper S1 at the end of its use in a root canal of average difficulty. Note how the dentinal debris is only on the coronal third of the instrument's blades. **B.** ProTaper S1 at the end of its use in a difficult root canal. Note how the dentinal debris are on most of the instrument's blades. In these cases the instrument must be considered disposable.

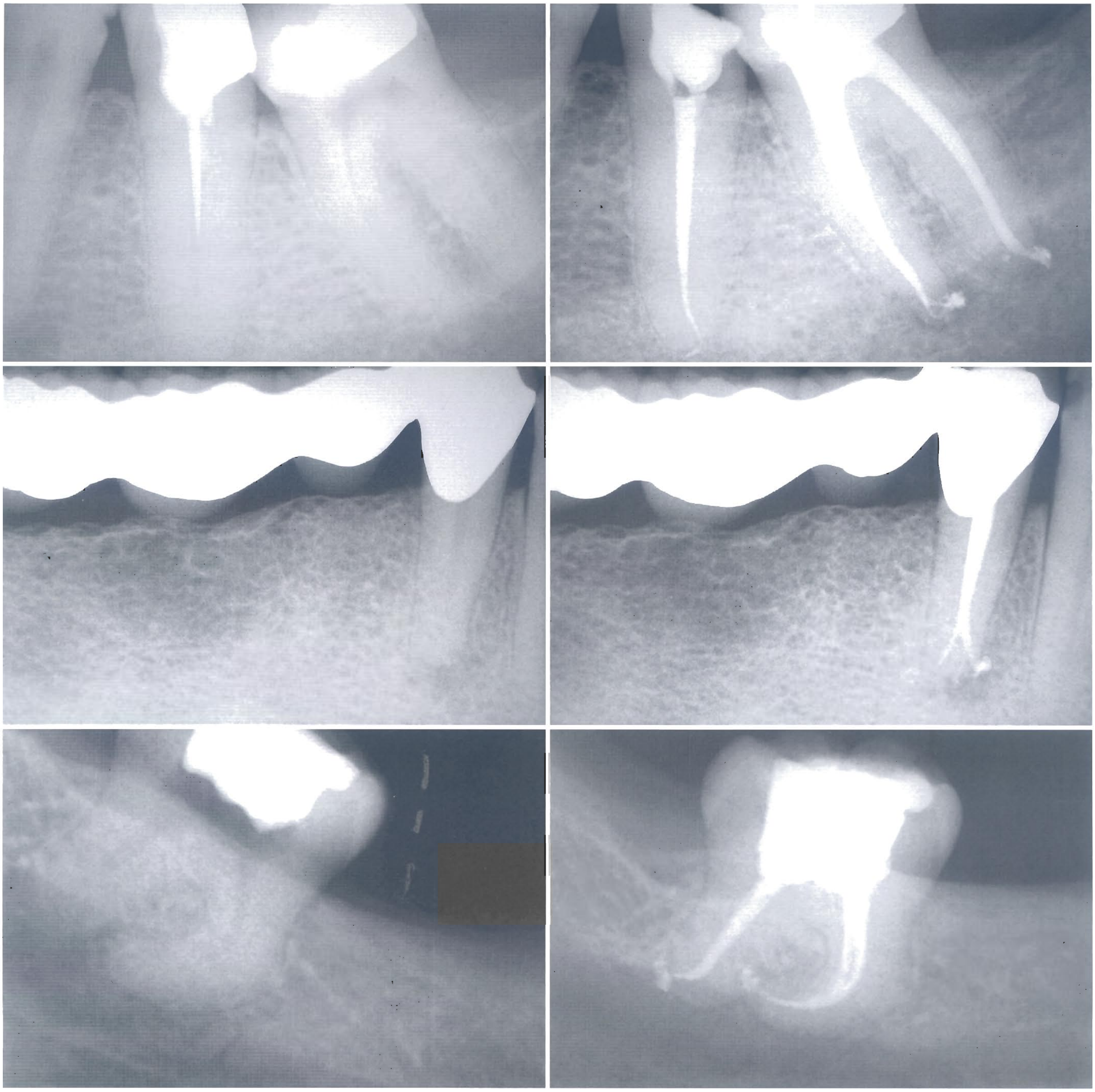


Fig. 18.41. Clinical cases of teeth with canals having an original complex anatomy in the apical one third. In these cases it is wise not to force the rotary NiTi instruments to the terminus of the canal. **A.** Preoperative radiograph of a lower left first molar. **B.** Postoperative radiograph (E. Berutti). **C.** Preoperative radiograph of the lower right first premolar. **D.** Postoperative radiograph (E. Berutti). **E.** Preoperative radiograph of the lower right third molar. **F.** Postoperative radiograph (G. Cantatore).

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