Rotary Nickel-Titanium Instrument Separation

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Rotary nickel-titanium instrument separation is an event that can easily turn an ordinary appointment into an undesirable experience. Although many times the long-term prognosis for the tooth is unchanged, the event casts a negative light on the root canal procedure for the patient and doctor. Understanding the physical and mechanical causes for rotary instrument separation is critical to preventing or limiting its occurrence.

Causes of rotary instrument failure can be divided into two main categories. The first category is cyclic fatigue failure and the second category is torque failure. Although these two causes are usually discussed independently, torque failure can be more likely to occur after an instrument has experienced cyclic fatiguing. Therefore, these two causes are not necessarily independent. The main causes of instrument separation along with some remedies to prevent instrument separation will be presented.

**Understanding Cyclic Fatigue Failure**

Cyclic fatigue is defined as the accumulated strain that develops from repeated bending of an object at the same location. The repeated bending action cycles tension and compressive forces. An example of cyclic fatigue is demonstrated when a paper clip is repeatedly bent at the same location. With every bend the paper clip becomes more fragile (fatigued) and eventually breaks. Rotation of endodontic instruments subjects them to both tensile and compressive forces in the area of curvature of the canal; with tensile forces on the outside of the curvature and compressive forces on the inside.
This phenomena is illustrated in figure 1 above. Rotary files experience cyclic fatigue when they are rotated in a curved canal, which causes the instrument to cycle in and out of compression and tension forces at the location of the curve. The main factors affecting cyclic fatigue in rotary endodontic instruments are radius of canal curvature, angle of canal curvature, speed of rotation, and instrument diameter (size)\(^2\).

Radius of canal curvature was found to be the most significant factor in determining cyclic fatigue in rotary endodontic instruments\(^1,2\). A more abrupt curve corresponds to a small radius of curvature. The smaller the radius of curvature of the canal the more likely the instrument was to separate from cyclic fatigue failure\(^1,2\).

\[\alpha_1 = 60^\circ, r_1 = 5mm\]
\[\alpha_2 = 60^\circ, r_2 = 2mm\]

**Fig. 2 Radius of canal curvature**
The above figure 2, taken from Pruett (2) illustrates the concept of canal curvature radius. Both teeth A and B have identical angles of curvature (60°), but tooth B has a much smaller radius of curvature and therefore a more abrupt curve. The above illustration shows that the parameters of angle of curvature and radius of curvature are independent of each other. Canals can have the same angle of curvature while having different radii of curvature, resulting in more abrupt curves.

Angle of canal curvature is defined by the angle formed by perpendicular lines drawn from the points of deviation that intersect the center of a circle. This is shown in the above figure 1, as the arc of the circle between point a and point b. In the study conducted by Pruett, it was shown that when the angle of curvature increased, the number of cycles to failure decreased 2.

A discussion of canal curvature analysis would not be complete without describing the Schneider method of determining root canal curvature. The Schneider method is perhaps the most common method for determining canal curvature in the endodontic literature. Schneider depicted canal curvature by a single parameter, an angle measured in degrees created by scribing a line parallel to the long axis of the canal, and a second line from the apical foramen, which intersected the first line at the point where the canal began to leave the long axis of the canal 3. Figure 3 below, illustrates the Schneider method of determining canal curvature.
Another variable that affects cyclic fatigue instrument failure is rotational speed of the instrument. A study conducted by Dietz concluded that rotational speed did influence the breakage of rotary nickel-titanium instruments by showing that a rotational speed of 150 rpm delayed instrument breakage caused by cyclic fatigue when compared with a rotational speed of 350 rpm. Contrary to the finding of Dietz was that rotational speed was not a significant factor affecting cyclic fatigue failure shown by Pruett. An important difference between these two studies was that Dietz looked at time to failure and Pruett looked at cycles to failure. The conclusion that can be made from looking at both studies is that the occurrence of cyclic fatigue failure is not affected by rotational speed but delaying the occurrence can be achieved by decreasing rotational speed.

Instrument diameter and more importantly instrument taper is yet another variable that influences cyclic fatigue instrument failure. This variable is one of clinical importance because the clinician has control over this variable, where as canal curvature and radius of curvature are fixed variables that are beyond the clinician’s control. Multiple studies, most notably Pruett, concluded that instrument diameter had a significant effect on cycles to failure. Cycles to failure significantly decreased with an increase in instrument size. The clinical relevance of this
principle would suggest that in curved canals or small radius curved canals, selecting an instrument with a .04 taper or .02 taper would be a safer choice to prevent cyclic fatigue instrument separation.

*Understanding torque failure*

The second main cause of instrument separation is torsional load or torque failure. Torque failure occurs when the rotational torque load applied to the instrument exceeds the torque limits of the instrument. An example of torque failure occurs when an instrument is forced apically under too much pressure and the tip binds under rotational force. Sattapan, showed that the average torque at failure increased with both file tip size and taper. Sattapan pointed out that an instruments torsional strength is directly related to its metal mass and therefore is influenced by tip size and taper of the instrument.

Instrument size is the most important factor related to torque failure. Instrument strength related to torque induced separation is directly correlated to the instrument cross-sectional surface area. As the cross-sectional diameter of the instrument increases, its resistance to torque induced separation increases. An important point to remember is that as the instrument diameter increases, the instrument cross-sectional surface area increases exponentially. This point is illustrated in the following chart:
<table>
<thead>
<tr>
<th>Tip diameter</th>
<th>Cross-sectional surface area</th>
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<tbody>
<tr>
<td>.20 mm</td>
<td>.031 mm²</td>
</tr>
<tr>
<td>.25 mm</td>
<td>.049 mm²</td>
</tr>
<tr>
<td>.30 mm</td>
<td>.071 mm²</td>
</tr>
<tr>
<td>.35 mm</td>
<td>.096 mm²</td>
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Although the difference in diameter between a size 20 instrument and a size 30 instrument is a 50% increase, the cross-sectional surface area is a 129% increase. The cross-sectional surface area difference between a size 20 instrument and a size 35 instrument is a 210% increase. The large percentage change in cross-sectional surface area occurs because the surface area of a circle = πr². The surface area increases as a square of the radius. This geometric feature of instrument size shows that using a slightly larger instrument size will greatly increase instrument metal mass and therefore instrument torque strength.

Torque related instrument failure has partially been remedied by the introduction of torque controlled auto-reversing motors. Torque controlled electric motors can be pre-set with torque limits just below the instrument torque limit so that the motor automatically reverses when the torque sensor reaches a certain torque. Torque controlled motors, when set just below the limit of elasticity for each instrument, reduce the risk of fracture markedly. It is important to remember that the limit of elasticity is different for different types and sizes of rotary instruments, therefore the proper torque limit must be selected for the individual instrument.

An instrument design feature that was specifically introduced to increase instrument strength and decrease instrument torque failure is a variable instrument core proportion. This may
actually be better described as variable flute depth. The proportion of the core diameter to the
outside diameter is greatest at the tip, where strength is most important. The proportion then
decreases uniformly as the fluting moves up the taper, resulting in greater flute depth and increases
flexibility while maintaining strength. Variable core diameter proportion is illustrated in figure 4.

Preventing instrument separation

Understanding the mechanical principles behind instrument separation aids the clinician in
the prevention or reduction of its occurrence. For example, knowing when the canal posses a
significant or small radius curvature which is more likely to cause a cyclic fatigue instrument
failure, it would be appropriate to use an instrument with an .04 taper. In canals with high cervical
curvatures or small radius curvatures, creating taper by stepping-back with .04 tapered instruments
will reduce cyclic fatigue. Less tapered, smaller diameter instruments are more resistant to cyclic
fatigue failure [1]. Creating straight-line access into canals is another method to reduce cyclic
fatigue. Removing high cervical bulges in the orifice region or impinging access walls, will
effectively create a straighter, less curved path for the instrument to follow and reduce cyclic fatigue.

Preventing torque-induced failure is a more difficult task. Utilizing a torque controlled electric motor, larger tip diameter instruments in straighter canals, and creating a glide path for the rotary instrument to follow are all techniques which will reduce torque induced instrument failure. Perhaps the most important skill for preventing torque-induced separation is the utilization of mild apical pressure when advancing a rotary instrument down a canal. This is an acquired skill and is often a test in patience.

**Other factors that affect instrument separation**

A review of the literature showed other relevant studies which investigated the effects of sodium hypochlorite and heat sterilization on instrument separation.

**Heat sterilization**

Silvaggio found that heat sterilization of rotary nickel-titanium files up to 10 times does not increase the likelihood of instrument separation. Silvaggio tested nine hundred ProFile instruments of different sizes sterilized 0, 1, 5, and 10 times in a steam autoclave, Statim autoclave, or dry heat sterilizer. The files were then divided and tested for torsional strength and flexibility. Fifty-two of 54 (96.3%) comparisons for torsional strength and 47 of 54 (87%) for rotational flexibility showed a significant increase or no change.

De Melo specifically examined the effects of heat sterilization on the fatigue resistance of nickel-titanium rotary instruments. De Melo examined both ProFile and Quantec brand files of similar taper, sterilized 0 and 5 times in a dry heat sterilizer. Following sterilization, the
instruments were subjected to cyclic fatigue testing in a steel artificial canal. Both ProFile and Quantece files showed a 70% increase in mean number of cycles to failure. Therefore the application of five sterilization procedures in dry heat increases the instruments resistance to cyclic fatigue failure.\(^9\)

It can be concluded from the two studies by De Melo and Silvaggio that not only does heat sterilization not increase instruments separation, but it may actually help prevent instrument separation. It should be pointed out that in the clinical setting a sterilization cycle always follows instrument use in a canal. Therefore, instruments sterilized multiple times will have more accumulated fatigue. This was not accounted for or discussed in either study.

**Effects of sodium hypochlorite on instrument separation**

Haikel investigated the mechanical properties of nickel-titanium files as a function of corrosion resistance with sodium hypochlorite.\(^{10}\) The mechanical properties studied were as follows: torsional moment (torque at failure), maximum angular deflection, maximum bending, and permanent angular deflection. A total of 80 instruments from 4 different manufacturers were tested. Half of the instruments were subjected to 2.5% sodium hypochlorite for 12 hours and the other half for 48 hours, and then their mechanical properties were tested. The study concluded that for all properties tested, sodium hypochlorite had no statistically significant effect.\(^{10}\)

In reviewing the scientific literature regarding rotary nickel-titanium instrument separation, it was found that an important mechanical study has been neglected. There is no published study that examines torque separation after an instrument has been cyclic fatigued. All currently available data relating to torque failure studies investigated torque limits of new instruments. Torque limits of new instruments are relevant for knowing how much torque an instrument can
sustain the first time it is inserted into the canal. A study that fatigued an instrument short of the instrument’s expected cyclic fatigue failure point then measured the torque failure limits would have clinical significance. This study design would show how cyclic fatigue influences torque failure. When an instrument accumulates cyclic fatigue it is likely that the instrument becomes more susceptible to torque failure. This scenario is more closely related to what happens during a clinical procedure.

There is no question that rotary nickel-titanium instruments have revolutionized the practice of endodontics. Rotary nickel-titanium instrumentation has produced more efficient, constant, predictable shapes than could be achieved by hand instrumentation. Nickel-titanium endodontic instruments also have a greater ability to negotiate curved canals; reduce the tendency of straightening, zipping, ledging, or perforating curved canals; and allow larger apical preparations of curved root canals while maintaining the original canal path. Along with all the benefits of rotary nickel-titanium instrumentation there is also an inherent risk of instrument separation. As is expected with any new technique, the advancement along the learning curve with rotary instrumentation will undoubtedly improve their safety of use and decrease the occurrence of breakage.
References


