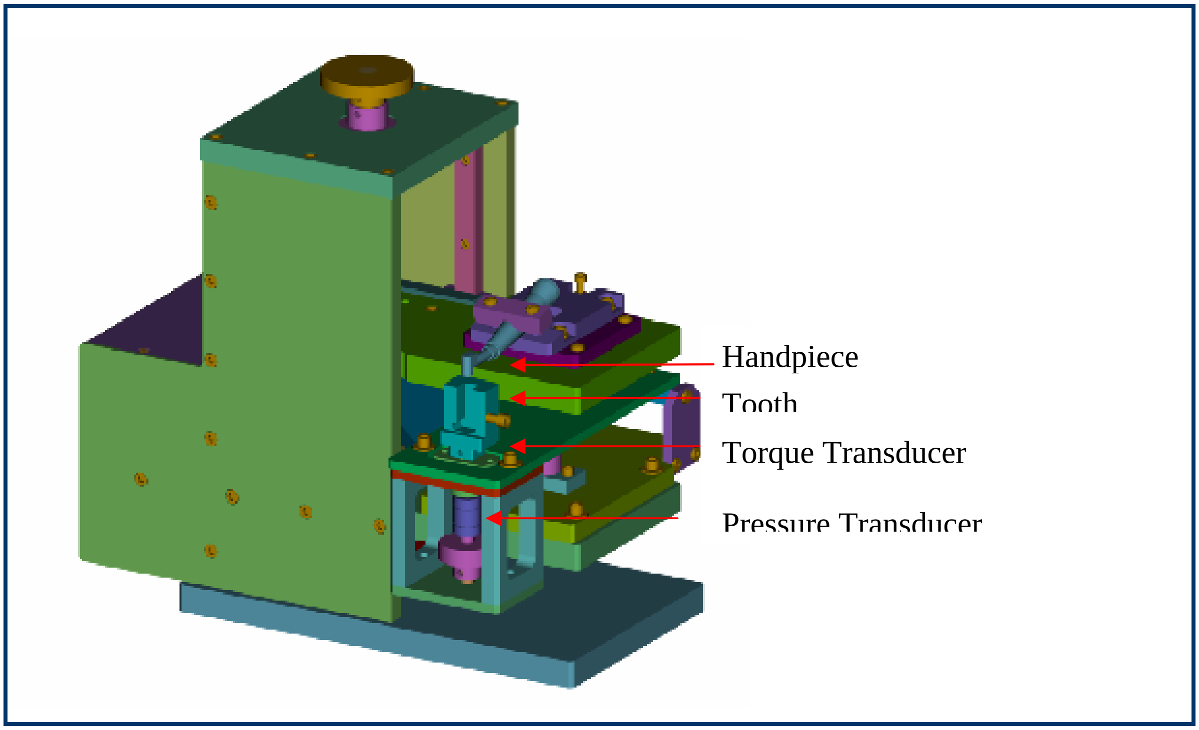
Section II. Ramifications of Design Considerations

18. How do we test designs?

To test the validity of the design considerations and ramifications, a clinical simulator was constructed to simultaneously measure torque, pressure and time during the prescribed use of instruments to determine efficiency and the threat of file failure. The simulator provides the means for precisely duplicating motions designed to simulate clinical applications for comparing one instrument to another. While eliminating operator variability and conforming to operation recommendations, computer programming can control the preparation parameters of depth and speed of file insertion and withdrawal, as well as speed of file rotation. Not only can the stress of each individual file be measured under different circumstances, but also the stresses using different file sequences can be recorded in order to determine the least stressful and most expeditious technique approaches. All measurements are plotted over time to illustrate when and how stress occurs.

Rather than measuring the over-all flexibility of the file, the simulator device can be used to measure dynamic flexibility, recording the resistance to bending as a rotating file progresses onto an inclined plane. The measurement occurs over time as different diameters of the file transverse a curvature.

The logged data help determine the methods for which each instrument may be used most effectively while minimizing the threat of failure. The simulations can be applied to different anatomies, and technique solutions quickly become apparent rather than having to rely on subjective and time-consuming trial and error experience that lack the benefit of controls. Examination of the results puts the manufacturer’s technique recommendations in perspective, validating or invalidating their claims. Identifying technique enhancements and file design improvements become more feasible.

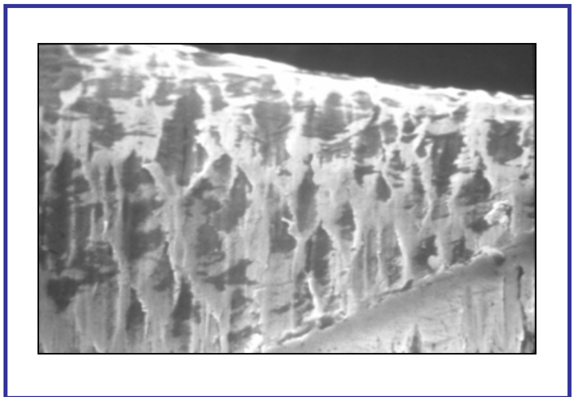


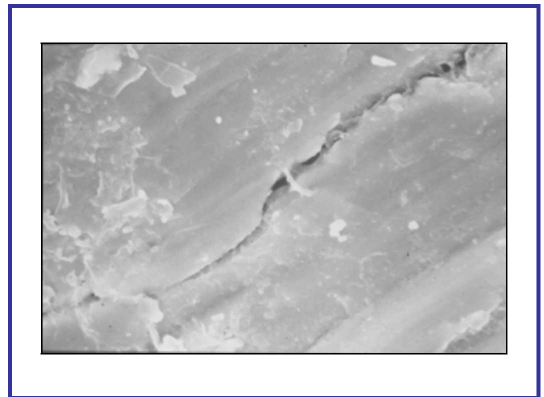
The clinical simulator inserts and withdraws a rotating file into a tooth or plastic block at programmable rates and depths while measuring torque and pressure over time. The tooth or plastic block is mounted on a weighted hinged stage that is free to travel in the same plane as the file to simulate the clinician's resistance to any screwing-in forces that might result from the rotation of the file.

The most important information afforded by the simulator is not the means to just avoid breakage but to minimize stress on the file, to distance the clinician from the possibility of failure. Although the simulator can facilitate the formulation of technique design, it does not eliminate the need to understand the causes of file failure and the means for avoiding it.

19. What causes breakage?

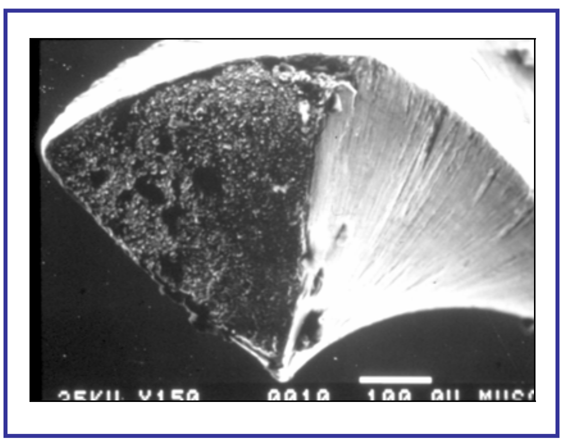
In the most basic terms, the strength of a file is due to the cohesive forces between atoms. As forces that tend to change the shape of the file are increasingly applied, the forces to separate atoms increase and their attractions decrease. Breakage occurs when the force of separation of the atoms exceeds the force of attraction. On a larger scale, the molecules of a metal are arranged in patterns denoting its crystalline structure or grain and the fracture of files usually can be characterized in two ways. One cause of fracture shows apparent deformation of a file and the separation occurs as a result of *slippage between the planes* of its crystalline boundaries most often due to the excessive forces of **torsion**. Another fracture may occur *across the grain* of the metal with little or no apparent deformation. This type of fracture can be seen as a result of **fatigue** most often caused from the excessive stresses of the repetitive rotation of a file during instrumentation around a curvature. Of course, most fractures are a *combination* of different forces of separation.

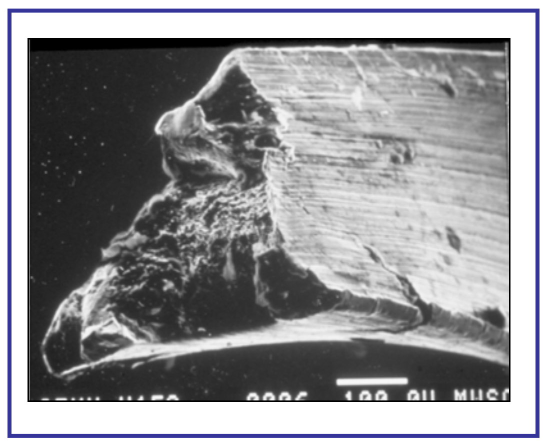




A ***B***

Irregularities in the surface of the leading edge of a file shown in image A act as stress concentration points for potential torque or fatigue failure. The force to propagate the crack shown in image B can be less than one half the forces that was required to form it. Examining the SEM images of the quality of manufacturing can provide valuable information for the probability for breakage.





C ***D***

The fracture across the grain of the metal of file C was probably the result of fatigue. Note the faults along the blade that are particularly susceptible to stress concentration.
The fracture resulting from slippage between the crystalline boundaries in file D was probably the result of excessive twisting.

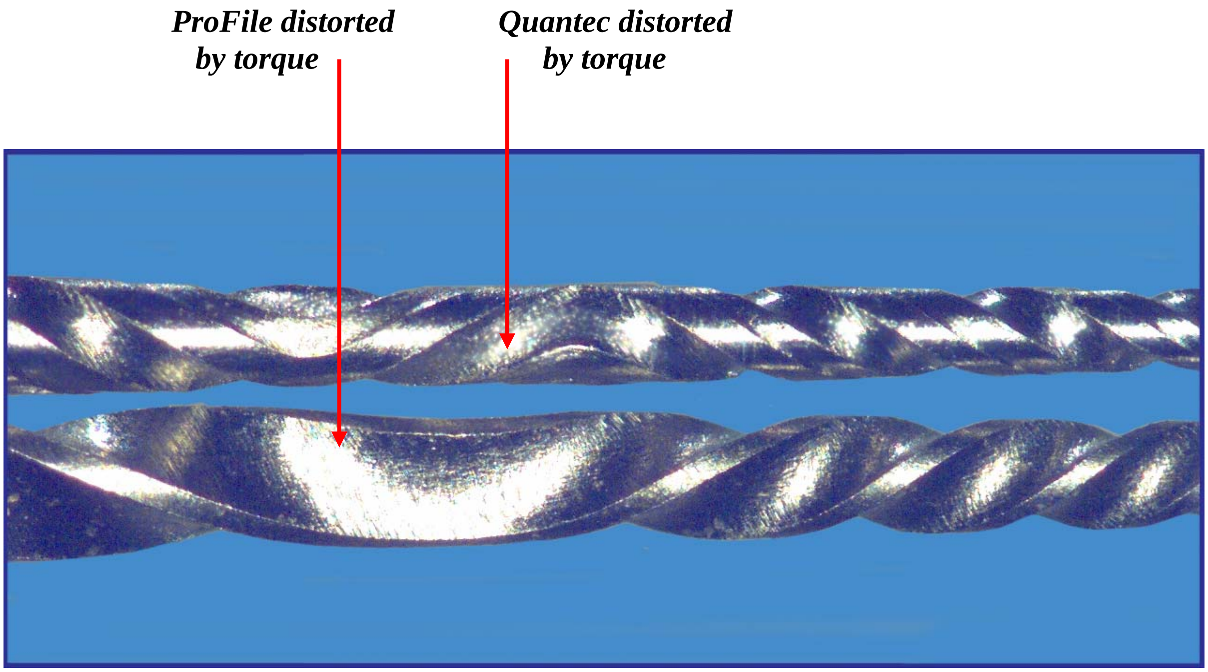
20. What is torsion?

Torsion is the axial force of being twisted when one part of a file rotates at a different rate than another part. Any distortion of a file that results from twisting, such as un-winding is caused by stress of torsion. When a file resists rotation during hand instrumentation with conventional .02 taper files, excessive torque can usually be tactilely perceived and file breakage can usually be avoided. On the other hand, even the use of torque limiting handpieces during rotary instrumentation does not provide the means for adjusting to varying circumstances, such as curvatures, the amount of file engagement, and the diameters of the file that are engaged. Any excessive torque as a result of these circumstances is not always avoided by preset torque limitations. On the other hand, the torque limits can be set so low that file failure would be difficult but effective canal enlargement would also be limited. Understanding the factors that cause excessive torque is the most reliable means for avoiding torsion failure.

21. What causes torsion stress?

Torsion stress on a file is primarily the result of (1) the force of cutting, how effectively a chip is formed and deflected from the wall of the canal, (2) the force of screwing-in due to the spiraled blades that become engaged in the wall of the canal without deflecting the chips that are formed, (3) the force of abrasion of the non-cutting surface of the file against the wall of the canal, (4) the force of distortion resulting from rotating in curvatures and (5) the force the debris exerts on the wall of the canal as it accumulates in the flutes. Incorporating designs to reduce any of these forces increases the file's efficiency and is one approach to advance instrument design. Another approach is to provide designs that can accommodate greater forces although the efficiency may remain unchanged.

A file with a larger diameter can resist more torsion stress than one with a smaller diameter. The relationship varies very closely with the square of the diameter. Therefore, a size .25 mm diameter can resist as much as 50% more torque than a size .20 mm diameter having the same design even though the difference in diameters is only .05 mm. The reason that the description *direct relation* between torque and diameter squired is not used is because the complicated variables in the crystalline structure of nickel titanium cause variations in the patterns of breakage.



*Nickel titanium has approximately the same torsion strength as stainless steel. The significant advantage of NiTi is its flexibility. Although NiTi's super-elastic ability to be distorted without permanent deformation is often cited as an attribute, this quality is of little consequence for a file rotating over 200 rpm. Some NiTi files may continue to twist as many as three times after becoming bound in the canal without failing compared to less than one revolution for stainless steel files, but, without warning, this may mean less than 1 second of reaction time for the operator***.** *A more meaningful relationship may be the torsion force required to fracture the file relative to its flexibility.*

Most files having the same size and taper usually distort in similar manners, however the force for distortion varies with file design.