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Influence of Manual Preflaring and Torque on the Failure Rate of ProTaper Rotary Instruments

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We evaluated the influence of manual preflaring and torque on the failure rate of rotary nickel-titanium ProTaper instruments Shaping 1 (S1), Shaping 2 (S2), Finishing 1 (F1), and Finishing 2 (F2). These factors were evaluated using an in vitro method by calculating the mean number of Endo-Training-Blocks shaped before file breakage under different conditions. Group A (S1 on simulators with no preflaring) shaped 10 blocks before failure, group B (S1 on manually preflared simulators) shaped 59 blocks ($p < 0.01$ versus group A), group C (S2 with low torque) shaped 28 blocks, group D (S2 with high torque) shaped 48 blocks ($p < 0.01$ versus group C), group E (F1 with low torque) shaped eight blocks, group F (F1 with high torque) shaped 23 blocks ($p < 0.01$ versus group E), group G (F2 with low torque) shaped four blocks, and group H (F2 with high torque) shaped 11 blocks ($p < 0.01$ versus group G). Manual preflaring creates a glide path for the instrument tip and is a major determinant in reducing the failure rate of these rotary nickel-titanium files. All instruments worked better at high torque.

In recent years, nickel-titanium (NiTi) alloy manual and rotary endodontic instruments have revolutionized endodontics. Thanks to the extraordinary superelasticity and strength of these alloys, rotary instruments with as much as 4-fold the taper of traditional manual instruments are now available (1–3). Consistent and efficient canal shaping is now possible with relatively few instruments (3–5).

The NiTi rotary instrument rotates continually within the root canal system and is subject to structural fatigue and ultimately failure because of two principal types of stress: bending stress and torsional stress (6, 7). The durability of a NiTi rotary instrument is directly proportional to the working stress it undergoes (8–10), and this is closely related to the number of cycles performed (7). Bending stress depends on the original anatomy of the canal and therefore cannot be influenced significantly by the clinician. Conversely, the endodontist can reduce the intensity of torsional stress. Although bending stress is most significant in terms of fatigue, excessive torsional stress is the main cause of instrument breakage (11).

Most rotary NiTi instruments have tip designs that confer poor cutting capability. If the tip encounters a portion of canal smaller than its diameter, the instrument tends to lock, and torque rises rapidly. If torque reaches a critical level, the instrument undergoes structural failure (12, 13). Based on these considerations, we hypothesized that manual preflaring would reduce instrument failure by reducing frictional forces applied to the file. Similarly, we hypothesized that a reduction in the applied torque would also reduce instrument failure. We tested these hypotheses using an in vitro use to failure design by evaluating the effect of these factors on the breakage rate of rotary NiTi ProTaper instruments applied to Endo-Training-Blocks.

MATERIAL AND METHODS

We tested the following rotary instruments: NiTi ProTaper Shaping 1 (S1), Shaping 2 (S2), Finishing 1 (F1), and Finishing 2 (F2) files (14–16). The salient characteristics of these instruments are a multiple taper on a single instrument, a convex-triangular cross-section, active blades, and a moderately active tip. Each instrument shaped a different canal portion:

- S1: coronal third, tip diameter 0.17 mm
- S2: middle third, tip diameter 0.20 mm
- F1: apical third, tip diameter 0.20 mm
- F2: apical third, tip diameter 0.25 mm

The working sequence was S1, S2, F1 at the working length, measurement of the apical foramen. If this was greater than a file size #20, then the F2 (#25) file was instrumented to the working length, and if necessary, a F3 (#30) was instrumented to the working length. The endodontic motor used was the Tecnika digital motor (ATR, Italy) with W & H WD-75M handpiece, 16/1 reduction (W & H, Bürmoos, Austria).

The rotation speed was set to 300 rpm. Artificial canals used were Endo-Training-Block simulators, taper 0.02, apex size #15 (Dentsply Maillefer). In this use to failure design, the outcome measure was the number of Endo-Training-Blocks each instrument shaped before file breakage.

TABLE 1. Experimental groups for evaluation of failure rate of ProTaper files

Group	Instrumentation on Endo-Training-Blocks	Torque*
A	S1 file used on new Endo-Training-Blocks (i.e. no preflaring)	6.80 Ncm (Tecnika motor setting 100)
B	S1 used on manually preflared Endo-Training-Blocks†	6.80 Ncm (Tecnika motor setting 100)
C	S2 used on manually preflared Endo-Training-Blocks after S1 reached the end of the canal†	1.36 Ncm (Tecnika motor setting 20)
D	S2 used on manually preflared Endo-Training-Blocks after S1 reached the end of the canal†	5.44 Ncm (Tecnika motor setting 80)
E	F1 used on manually preflared Endo-Training-Blocks after S1 and S2 reached the end of the canal†	1.90 Ncm (Tecnika motor setting 28)
F	F1 used on manually preflared Endo-Training-Blocks after S1 and S2 reached the end of the canal†	6.80 Ncm (Tecnika motor setting 100)
G	F2 used on manually preflared Endo-Training-Blocks after S1, S2, and F1 reached the end of the canal†	2.72 Ncm (Tecnika motor setting 40)
H	F2 used on manually preflared Endo-Training-Blocks after S1, S2, and F1 reached the end of the canal†	6.80 Ncm (Tecnika motor setting 100)

* Endodontic motor was a Tecnika digital motor with W & H WD-75M handpiece, 16/1 reduction.

† Manual preflare protocol (the working sequence utilized K-Files #10 and #15 (Dentspy Maillefer) and NiTi 20 (NiTiFlex File, Dentspy Maillefer) until file 20 reached the working length, with feed and pull movement).

TABLE 2. Number of simulators shaped per group

File #	1	2	3	4	5	6	7	8	Mean ± SD
Group A S1 in new Endo-Training-Blocks	10	10	8	12	10	11	9	9	9.9 ± 1.2
Group B S1 in preflared Endo-Training-Blocks	58	57	60	59	60	61	59	58	59.0 ± 1.3 $p < 0.01$ versus group A
Group C S2 at low torque	26	28	30	29	28	27	29	27	28.0 ± 1.3
Group D S2 at high torque	48	48	46	49	50	47	47	50	48.1 ± 1.5 $p < 0.01$ versus group C
Group E F1 at low torque	7	10	8	7	8	7	9	8	8.0 ± 1.1
Group F F1 at high torque	22	23	22	25	23	21	26	22	23.0 ± 1.7 $p < 0.01$ versus group E
Group G F2 at low torque	5	3	4	6	4	3	4	4	4.1 ± 1.0
Group H F2 at high torque	10	11	11	9	12	10	11	12	10.8 ± 1.0 $p < 0.01$ versus group G

The experimental groups ($n = 8$ instruments/group) are listed in Table 1. As described, each instrument was taken to the working length only once with very light pressure on the handpiece; no irrigants were used. One endodontist tested the first four files (#1–#4) for each group, and a second endodontist tested the next four files (#5–#8) for each group.

Data were analyzed by *t* test by comparing between groups A and B, C and D, E and F, and G and H as determined a priori. Significance was taken as $p < 0.05$.

RESULTS

The results are shown in Table 2 with the outcome measure consisting of the mean number of Endo-Training-Blocks instrumented before file breakage was detected. The results indicate that the manual preflaring produced nearly a 6-fold increase in the number of Endo-Training-Blocks instrumented by S1 files before failure was observed (group A versus B; $p < 0.01$). In addition, the use of high torque applied to the S2, F1, and F2 files produced statistically significantly more usage before instrument failure (groups D versus C, F versus E, and H versus G; $p < 0.01$ for all comparisons). In addition, statistical analysis did not detect any significant difference between the results obtained by the two endodontists.

DISCUSSION

We used Endo-Training-Blocks with a uniform taper of 0.02 and an apex equivalent to a size #15 (Dentsply, Maillefer) to standardize, as far as possible, the stress each instrument underwent during each use. We found very high constancy of working length and curvature among the different Endo-Training-Blocks used. Anatomical variability can thus be ruled out, and the parameters of interest were evaluated alone.

When shaping the canal system, rotary NiTi instruments cyclically undergo stress that causes fatigue (6). Fatigue is caused by two chief types of stress: bending and torsion (6). Torsional stress can rapidly cause instrument breakage. This generally occurs in three situations:

(a) when extensive instrument surface encounters excessive friction on canal walls (locking) (17)

(b) when the instrument tip is larger than the canal section to be shaped (12, 18)

(c) when excessive pressure is put on the handpiece (19)

The majority of today's greater-taper rotary NiTi instruments have inactive or moderately active tips to prevent the formation of steps, false paths, or transportation of the apical foramen. Although such design features minimize the risk of these procedural errors, they do not preclude other procedural problems—for example, when a tip with little to no cutting capability encounters a portion of canal with a cross-section smaller than the tip diameter. Under these conditions, the tip may lock, leading to large and rapid increases in torsional stress. The torque developed by the motor may then exceed a critical level, and the instrument immediately undergoes plastic deformation and failure (12). In our opinion, this situation, together with the complexity of the original anatomy, appears to be the most frequent cause of instrument breakage. It is thus indispensable to create a glide path (manual preflaring) for the tip of the instrument (16, 18). An initial brief manual instrumentation enables

- torsional stress to be drastically reduced, because the canal width becomes at least equal to the diameter of the tip of the instrument to be used
- the original anatomy to be understood

ProTaper S1 has a tip of 0.17 mm; the canals of the Endo-Training-Blocks have taper 0.02 and apex 0.15 mm. This slight discrepancy between canal diameter at the apex and tip size of S1 was sufficient to cause a great difference in the number of specimens shaped. In group B, in which the glide path had been created by brief manual preflaring (file 20 to the apex), the S1 file shaped an average 59 simulators (reaching the apex) before failure. In contrast, manual preflaring avoided the tip of S1 developing torsion on entering canal region with small cross-sectional diameter. This large reduction in torsional stress increased the average instrument life almost 6-fold. The clinical significance of this difference translates into reduced costs and a reduced risk of separating the instrument within the canal.

The second part of our research evaluated how different torque settings influence the failure rate of ProTaper S2, F1, and F2 instruments. In groups D (S2), F (F1), and H (F2), in which high torque was used (torque setting 100, equal to 6.80 Ncm), all instruments shaped a significantly higher number of simulators before breaking compared with groups C (S2), E (F1), and G (F2), in which the torque setting was lower. It is our opinion that this remarkable and constant difference in instrument life was caused by the endodontic motor frequently engaging auto-reverse at low torque, whereas at high torque, auto-reverse was never engaged. Auto-reverse is not itself deleterious, especially for instruments that must be used with low maximum torque. However, because clockwise rotation is engaged when a maximum torque value is reached, the instrument performs work. This means the instrument stores stress, and hence, its service life is reduced. Superfluous work for the rotary NiTi instrument must be avoided if possible. If an instrument must be used at low torque, then the operator should be guided by the motor's digital and acoustic signal and remove the instrument before auto-reverse engages. This minimizes superfluous stress, and therefore, instrument service life is consumed solely in cutting dentin.

The results of this study show that similar instruments perform similar amounts of work. This finding indicates high manufacturing standardization, and indeed, no premature breakages occurred. However, each instrument in the ProTaper series (S1, S2, F1, F2) has a different life expectancy, depending on instrument size and type of work performed within the canal. In optimal working conditions, we found that the life of each category of instruments was as follows:

- S1: 59 simulators to breakage; the multitaper of S1 limits its use to the apical third of the canal
- S2: 48 simulators to breakage; the multitaper of S2 limits its use to the median third of the canal

These two instruments in these conditions are very long-lasting. They work in the initial stretch of the canal and use their largest and strongest parts. S2 works in a deeper part of the canal and its life is 20% shorter than S1.

- F1: 23 simulators to breakage
- F2: 11 simulators to breakage

These two instruments shape the apical third of the canal. They undergo fairly high bending and torsional stress in their thinner and weaker part (apical 3 mm). The life expectancy of F1 is 60% less than S1, and that of F2 is 80% less than S1. F2 is shorter-lasting than F1 because F2 accumulates more torsional stress, creating greater taper in the apical third (0.08 for F2 versus 0.07 for F1) and a larger apical foramen (F2 = 0.25 mm, F1 = 0.20 mm).

These data suggest that the type of work performed by a rotary NiTi instrument within the root canal is very important (8, 9). The work performed and the specifics of canal anatomy are the most important factors affecting instrument life (20). However, it must not be forgotten that the capability of the endodontist in applying this information is also a determinant for success.

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References

1. Walia H, Brantley WA, Gerstein H. An initial investigation of the bending and torsional properties of nitinol root canal files. J Endodon 1988;14:346–51.
2. Walia H, Costas J, Brantley W, Gerstein H. Torsional ductility and cutting efficiency of the Nitinol file. J Endodon 1989;15:174 (abstract 22).
3. Cantatore G. Evolution des techniques d'instrumentation canalair. Eur Dent Mag Le Monde Dentaire 1998;87:11–25.
4. Glosson CR, Haller RH, Dove SB, del Rio CE. A comparison of root canal preparations using NiTi hand, NiTi motor-driven and K-Flex endodontic instruments. J Endodon 1995;21:146–51.
5. Thompson SA, Dummer PMH. Shaping ability of ProFile 04 Taper Series 29 rotary nickel-titanium instruments in simulated root canals. Int Endod J 1997;30:1–7.
6. Sotokawa T. An analysis of clinical breakage of root canal instruments. J Endodon 1988;14:75–82.
7. Pruett JP, Clement DJ, Carnes DL Jr. Cyclic fatigue testing of nickel-titanium endodontic instruments. J Endodon 1997;23:77–85.
8. Zuolo ML, Walton RE. Instrument deterioration with usage: nickel-Titanium vs stainless steel. Quintessence Int 1997;28:397–402.
9. Yared GM, Bou Dagher FE, Machtou P. Cyclic fatigue of ProFile rotary instruments after simulated clinical use. Int Endod J 1999;32:115–9.
10. Gambarini G. Cyclic fatigue of ProFile rotary instruments after prolonged clinical use. Int Endod J 2001;34:386–9.
11. Sattapan B, Nervo GJ, Palamara JEA, Messer HH. Defects in rotary nickel-titanium files after clinical use. J Endodon 2000;26:161–5.
12. Gambarini G. Rationale for the use of low-torque endodontic motors in root canal instrumentation. Endodon Dent Traumatol 2000;16:95–100.
13. Yared GM, Bou Dagher FE, Machtou P, Kulkarni GK. Influence of rotational speed, torque and operator proficiency on failure of Greater Taper files. Int Endod J 2002;35:7–12.
14. West JD. Introduction of a new rotary endodontic system: progressively tapering files. Dent Today 2001;20:50–7.
15. Ruddle CJ. The ProTaper technique: endodontics made easier. Dent Today 2001;20:58–68.
16. Ruddle CJ. The ProTaper endodontic system: geometries, features, and guidelines for use. Dent Today 2001;20:60–7.
17. Blum JY, Cohen A, Machtou P, Micallef J-P. Analysis of forces developed during mechanical preparation of extracted teeth using ProFile NiTi rotary instruments. Int Endod J 1999;32:24–31.
18. Roland DD, Andelin WE, Browning DF, Hsu G-HR, Torabinejad M. The effect of preflaring on the rates of separation for 0.04 taper NiTi Rotary instruments. J Endodon 2002;28:543–5.
19. Kobayashi C, Yoshioka T, Suda H. A new motor-driven canal preparation system with electronic canal measuring capability. J Endodon 1997;23:751–4.
20. Sattapan B, Palamara JEA, Messer HH. Torque during canal instrumentation using rotary nickel-titanium files. J Endodon 2000;26:156–60.