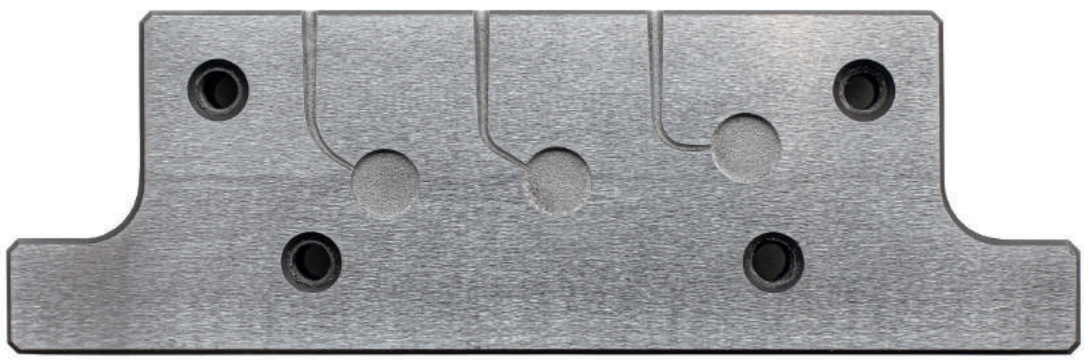
Impact of reciprocal and OTR motion on mechanical NiTi files' resistance to fracture in cyclic fatigue testing and during canal preparation in resin blocks

Dr Sławomir Gabryś, Poland



1

Fig. 1: The custom-made device with artificial stainless-steel canals for cyclic fatigue tests.

Introduction

It has been over 30 years since endodontic hand files made of nickel-titanium (NiTi) alloy were first used in 1988.[1] This fact provided an opportunity to introduce to the market rotary NiTi files with tapers of larger than .2 in 1992.[2] Root canal preparation with engine-driven files revolutionised this very important stage of root canal therapy, which has become quicker and more effective.[3] At the same time, maintaining the original canal path has become easier than with files made of stainless steel.[4] However, apart from the obvious advantages of using rotary NiTi files, we can also find some disadvantages. One of these weaknesses is a possibility of fracturing a file inside a root canal. The fracture frequency of rotary files, as illustrated by the research conducted on many cases at the University of Pennsylvania's School of Dental Medicine in the US and at Nanjing Stomatological Hospital in China, equals approximately 2 per cent of cases.[5,6] For a clinician, that is an unwelcome event which may hinder or even make a disinfection of the entire root canal system totally impossible.[7] Thanks to the endodontic microscope and ultrasound, it is possible to remove fractured files from canals;[8] however, there is always the risk of widening the canal too much and, in consequence, weakening the root or causing a perforation.[9]

We may distinguish two mechanisms which may cause file fracture. The first one is cyclic fatigue failure, and the second is torsional fatigue failure.[10] A file rotating in a curved canal undergoes cyclic tension (concerning the surface of a file situated on the external wall of the curvature) and compression (concerning the surface of a file situated on the internal wall of the curvature). Cyclic tension and compression repeated with every rotation lead to material fatigue and, in consequence, to file fracture.[11]

A file which widens a canal also undergoes torsional stress resulting from dentine cutting. If the elastic limit of the alloy is exceeded, the file fractures owing to torsional fatigue failure.

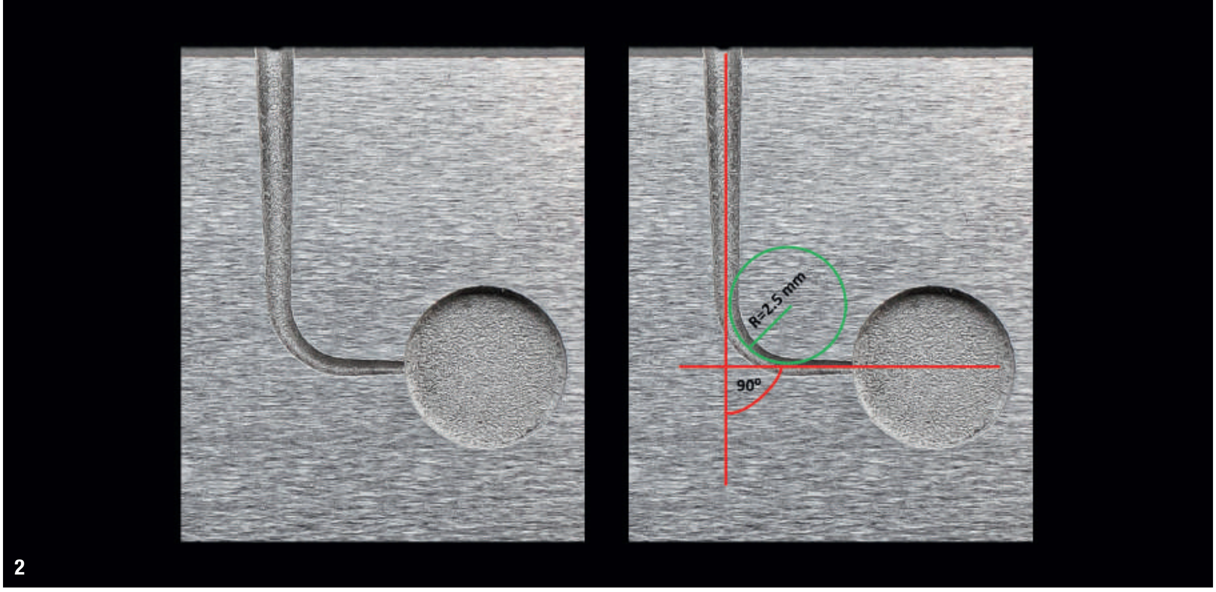


Fig. 2: An artificial canal used in this study: 16 mm in length, 90° angle of curvature and 2.5 mm radius of curvature.

There are plenty of factors influencing file fracture: the operator's experience, instrumentation technique (access, sequence used, glide path), instrument design and heat treatment of its alloy, degree and radius of the canal's curvature, parameters set on the endodontic motor (speed, torque) and the type of file motion (continuous rotation, reciprocation, Optimum Torque Reverse).[12]

The aim of the present study was to investigate the impact of reciprocal motion and Optimum Torque Reverse motion on file fracture in cyclic fatigue testing and during the preparation of artificial canals in resin blocks, where a file apart from working in a curved canal has to widen this canal. The files used in the test were RECIPROC blue R25 (VDW) and Endostar E3 Azure 25/.06 (Poldent).

RECIPROC blue R25 files are thermally treated NiTi instruments and have a nominal size of 0.25 mm at the tip and a taper of 0.08 mm/mm in the last 3 mm from the tip. The instruments have an S-shaped cross section. These are left-cutting files designed to operate in reciprocal motion.

Endostar E3 Azure 25/.06 files are thermally treated NiTi instruments and have a nominal size of 0.25 mm at the tip and a constant taper of 0.06 mm/mm. They also have an S-shaped cross section. These are right-cutting files designed to operate in rotary, reciprocal and Optimum Torque Reverse motion.[13]

Both instruments (RECIPROC blue and Endostar E3 Azure) undergo post-manufacture complex heating–cooling proprietary treatments that result in a visible titanium oxide layer on the surface of the instrument which gives the characteristic blue colour. This treatment changes the transition temperatures between martensitic phase and austenitic phase, which is claimed by the manufacturers to result in superior mechanical properties of the NiTi instruments.

Reciprocal motion for canal preparation was proposed by Yared in 2008.[14] In such motion, the file performs alternately partial clockwise (CW) rotation and partial counterclockwise (CCW) rotation. This partial rotation is referred to in degrees, for example 180° CW and 90° CCW, which means that a file alternately moves half of the rotation CW and then a quarter of the rotation CCW. So, for the file to make a full rotation (360°), it needs four cycles CW and CCW. The use of reciprocating motion was shown to extend the lifespan of a NiTi instrument.[15] The recommended reciprocal motion for the RECIPROC blue R25 file is 150° CCW and then 30° CW rotation at a speed of 300 rpm.[16]

Optimum Torque Reverse (OTR) motion was patented by J. Morita in 2015. This new motion was introduced to exploit reciprocation's benefits and minimise its disadvantages, such as increased transportation of the debris towards the apex.[17] OTR motion combines rotary motion with reciprocation. When a file is inserted into the canal, it rotates 360° CW, and when the force acting on the file is too large, the file reverses its rotation in a CCW direction by 90° and then continues rotation in the CW (cutting) direction for 180°. During this half rotation in the cutting direction, sensors of the handpiece calculate the force acting on the file. If the force is too large, the file will automatically reverse rotation again (90° in the CCW direction) and then it will rotate in the CW direction for 180° and the motor will calculate the acting force again. So, if the force acting on the file is constantly too large, the file performs a reciprocal motion (180° CW and 90° CCW). If the force acting on the file is small, the file constantly rotates in the CW direction.[18] One can set five levels of torque to activate reciprocal motion in OTR motion: 0.2 Ncm, 0.4 Ncm, 0.6 Ncm, 0.8 Ncm and 1.0 Ncm. The smaller the torque that is set, the more often the file works in reciprocation (90° CCW and 180° CW). All right-cutting files, like Endostar E3 Azure, can operate in OTR motion.

Materials and methods

For the test, the following files were used: 40 new RECIPROC blue R25 files with a 0.25 mm tip size and a variable taper (.08 at the tip to 0.04 at the shaft) and 40 new Endostar E3 Azure 25/.06 files with a 0.25 mm tip size and a constant taper of .06. All instruments used were 25 mm long. The files were examined under a stereomicroscope (Leica M50, Leica Microsystems) at

Fig. 3: Micro-caliper for measuring fractured instruments.

20× magnification. No defects or deformations were detected; thus, all the files were subjected to this study.

The study consisted of two parts. The first was a cyclic fatigue resistance test, and the second was preparation of canals in resin blocks.

Cyclic fatigue resistance test

Twenty RECIPROC blue R25 and 20 Endostar E3 Azure 25/.06 files were used for this test. A total of 40 instruments were divided randomly into four groups (each group included ten instruments of the same brand; $n=10$) depending on the motion being tested:

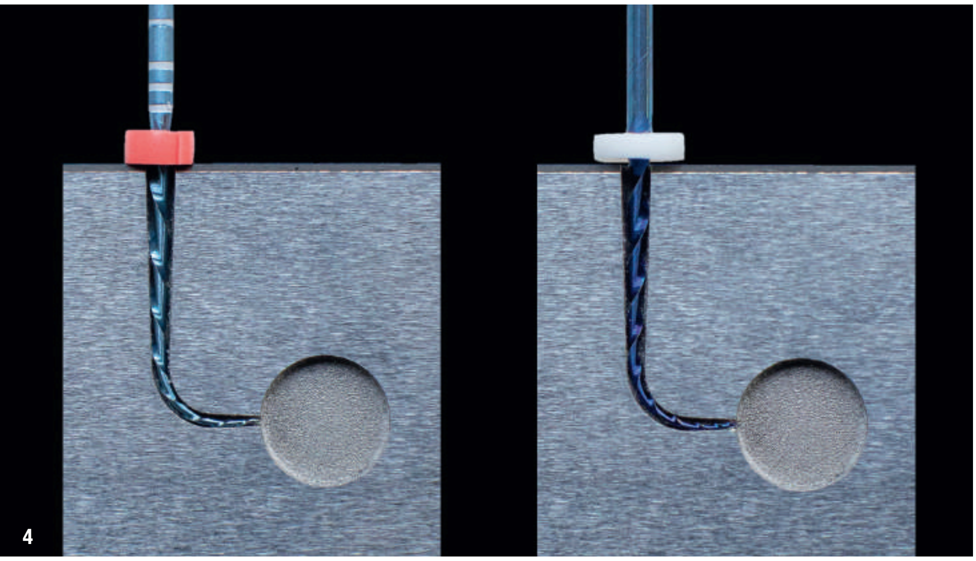
– Group 1: RECIPROC blue R25 in continuous rotation CCW at 300 rpm and a torque of 2 Ncm
– Group 2: RECIPROC blue R25 in reciprocation (“RECIPROC ALL” programme)
– Group 3: Endostar E3 Azure 25/.06 in continuous rotation CW at 300 rpm and a torque of 2 Ncm
– Group 4: Endostar E3 Azure 25/.06 in reciprocation of OTR motion with the activation torque set at the lowest level (0.2 Ncm) so that a file in an artificial canal constantly worked in reciprocal motion 180° CW to 90° CCW and at a speed of 300 rpm.

The files were tested on a custom-made device with an artificial stainless-steel canal (Fig. 1). The device was made according to the guidelines described by Plotino et al. in 2010.[19,20] The artificial canal was 16 mm long and had a 90° angle of curvature and a 2.5 mm radius of curvature (Fig. 2).

The instruments were driven by two electric motors depending on the motion used. The Endostar Provider endodontic motor (J. Morita) was used for Groups 1, 3 and 4, and VDW.SILVER RECIPROC (VDW) was used for Group 2. To decrease the friction between the instruments and artificial canal walls, WD-40 synthetic oil (WD-40 Co.) was sprayed into the artificial canal before use of each file. The instruments rotated/reciprocated freely inside the simulated canal until fracture occurred. The time to fracture was measured (in seconds) using a digital stopwatch (Junsd JS-307, Shenzhen JUNSD Industry Co.). Next, each fractured instrument was measured with a digital micro-caliper (Magnusson, Fig. 3) with an accuracy of 0.02 mm, to check that each file was positioned in the canal to the same depth (Fig. 4).

Preparation of canals in resin blocks

Twenty RECIPROC blue R25 and 20 Endostar E3 Azure 25/.06 files were used for this test. A total of 40 instruments were divided randomly into four groups (each group contained ten instruments of the same brand; $n=10$) depending on the type of motion used in the resin block:



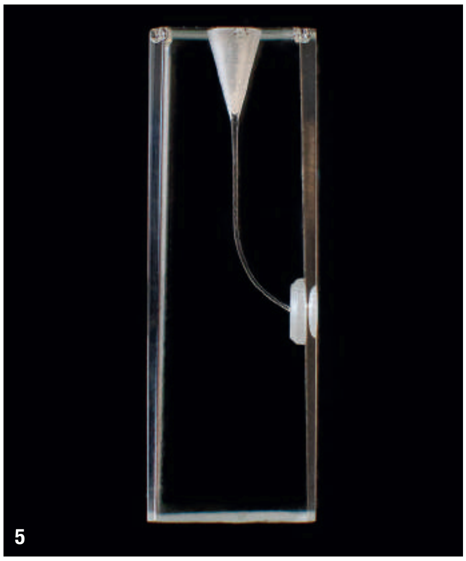


Fig. 4: Positioning of the files inside artificial canals: on the left RECIPROC blue R25 and on the right Endostar E3 Azure 25/.06. **Fig. 5:** Edodontic training blocks with an artificial canal 18.5 mm long with a 55° curvature in the apical area.

Table 1

Group	TtF Mean (SD)	FL Mean (SD)
Group 1	31.2 (2.90)	4.01 (0.34)
Group 2	40.1 (3.35)	3.95 (0.32)
Group 3	89.6 (6.33)	3.78 (0.29)
Group 4	217.3 (23.25)	3.79 (0.41)

Table 2

Group	NPB Median (SD)
Group 1	7 (1.20)
Group 2	9 (1.10)
Group 3	10 (1.10)
Group 4	14 (1.29)

Table 1: Means and standard deviations of the time to fracture (TtF) in seconds and the fractured fragment length (FL) in millimetres. **Table 2:** Medians and standard deviations of the number of prepared blocks (NPB) until file fracture occurred.

- Group 1: RECIPROC blue R25 in continuous rotation CCW at 300 rpm and a torque of 2 Ncm
- Group 2: RECIPROC blue R25 in reciprocation ("RECIPROC ALL" programme)
- Group 3: Endostar E3 Azure 25/.06 in continuous rotation CW at 300 rpm and a torque of 2 Ncm
- Group 4: Endostar E3 Azure 25/.06 in reciprocation of OTR motion with the activation torque set at the lowest level (0.2 Ncm) so that a file in the artificial canal constantly worked in reciprocal motion 180° CW to 90° CCW and at a speed of 300 rpm.

The tests were run on resin endodontic training blocks (VDW) containing an artificial canal 18.5 mm long with a 55° curvature in the apical area (Fig. 5). Each file was used to prepare canals in consecutive resin blocks until the file fractured. The number of blocks prepared until fracture occurred for each file was noted down, including the block in which fracture occurred.

All the canals were instrumented by just one operator (the author of the article). The blocks were installed in a bench vice to secure their stability during the canal preparation. The patency of the canal was first determined with a size 10 K-type file (Poldent). The file was inserted into the canal until the tip could be seen in the foramen. Next, the canal was widened to size 20/.02 with a size 20/.02 Endostar NT2 file (Poldent) to the working length (18 mm). The aim was to standardise the canals in the blocks so that the files worked in the canals with the same initial size. Thereafter, the proper canal preparation started. With the RECIPROC blue file or Endostar E3 Azure file, four cycles were made including three pecking movements in the apical direction. In the fourth cycle, the working length of 18 mm was reached. Between every cycle, the canal was irrigated with distilled water from a syringe with a side-vented needle. Next, the size 10 K-type file was inserted until the tip of the file was visible in the apex (patency), and again the canal was irrigated with distilled water. Between cycles, file edges were cleaned on a sponge. After achieving working length, the canal was considered prepared and the work with the same file was continued in the next blocks until fracture occurred.

Statistical analysis

Statistical analysis was performed with the IBM SPSS programme (Version 25.0, IBM Corp.). To check significant statistical differences among groups, the Kruskal–Wallis test was performed. When significant statistical differences occurred, the Games–Howell post-hoc test was used. It helped to identify among which groups exactly significant statistical differences occurred. The choice was made based on homogeneity variances in compared groups. The level of $p < 0.05$ was considered statistically significant.

Results

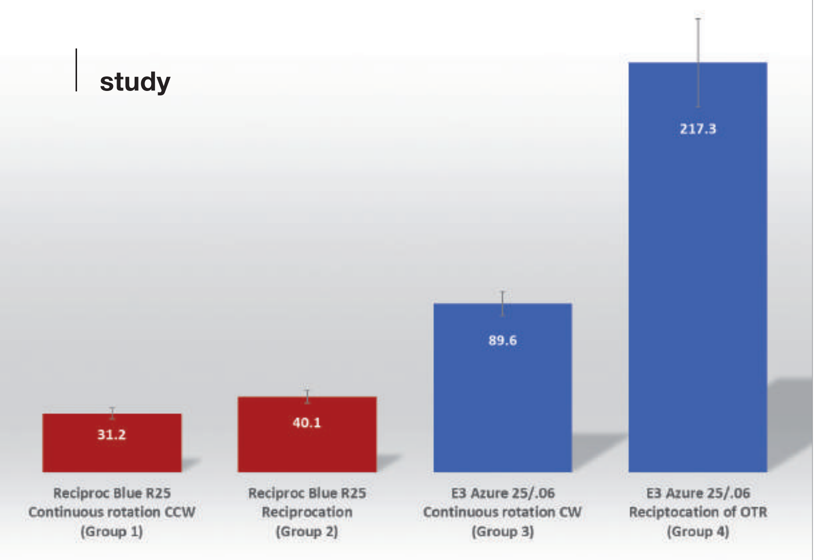
Cyclic fatigue resistance test

The means and standard deviations of the time-to-fracture values (in seconds) of the tested groups are shown in Table 1. The analysis showed statistically significant differences among all four tested groups ($p < 0.001$). Group 4 gained the highest results in comparison with the remaining three groups. Group 1 gained the lowest results. Comparing the influence of the type of motion (continuous rotation vs reciprocation) on time to fracture for the same type of files (Group 1 vs Group 2; Group 3 vs Group 4), statistically significant prolongation of time to fracture occurred in reciprocal motion dedicated to RECIPROC files and in OTR reciprocal motion ($p < 0.001$; Fig. 6).

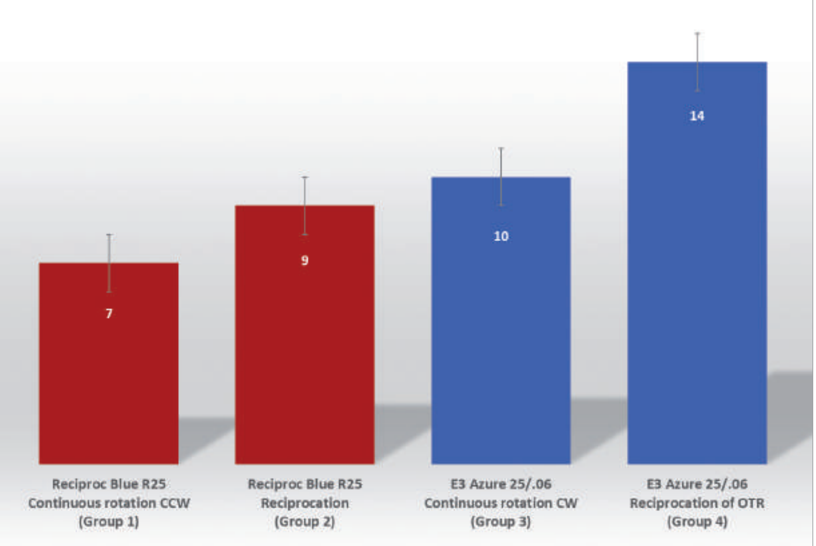
The means and standard deviations of the length of the fractured fragments (mm) are also shown in Table 1. The analysis did not show statistically significant differences in the length of the fractured fragments ($p > 0.05$).

Preparation of canals in resin blocks

The medians and standard deviations of the number of prepared blocks until fracture for all tested groups are shown in Table 2. Statistically significant differences concern all groups compared with one another ($p < 0.001$),



6



7

Fig. 6: Mean time to fracture in seconds. Red bar: RECIPROC blue R25 (continuous rotation vs reciprocation). Blue bar: Endostar E3 Azure 25/.06 (continuous rotation vs OTR reciprocation). **Fig. 7:** Median number of prepared blocks. Red bar: RECIPROC blue R25 (continuous rotation vs reciprocation). Blue bar: Endostar E3 Azure 25/.06 (continuous rotation vs OTR reciprocation).

except for the comparison of Group 2 with Group 3. The median number for Group 4 turned out to be the highest in comparison with the remaining groups. The opposite was true for Group 1: it achieved the lowest median value of the analysed variable. Comparing the influence of the type of motion (continuous rotation vs reciprocation) on the number of prepared blocks until fracture (Group 1 vs Group 2; Group 3 vs Group 4), a statistically significant increase in the number of prepared blocks occurred for both reciprocal motions: dedicated to RECIPROC files and OTR motion ($p < 0.001$; Fig. 7).

Discussion

The research showed a longer lifespan of NiTi rotary files operating in two types of reciprocal motion. Both reciprocal motions (the one dedicated to RECIPROC blue files and OTR motion for Endostar E3 Azure files) extended the time to fracture in a cyclic fatigue test and increased the number of canals prepared in resin blocks before fracture.

Often, cyclic fatigue tests are performed to compare resistance to fatigue of particular files which differ in design, for example cross section, heat treatment (or the lack of it) and different manufacturing processes.[21–23] This research concentrated on the influence of the type of motion on resistance to fatigue. It was not the author's intention to compare RECIPROC blue R25 to Endostar E3 Azure 25/.06 in cyclic fatigue resistance tests because the comparison of these two files would be unreliable owing to their different width at the breaking point (about 4 mm from the apex). These files have a different taper in the last few millimetres from the tip. The RECIPROC blue R25 has a taper of .08 in the last 3 mm from the tip; therefore, its width in the third millimetre equals 0.49 mm, whereas Endostar E3 Azure 25/.06 has a stable taper of .06, and its width in the third millimetre from the tip equals 0.43 mm. The Endostar E3 Azure file is 0.49 mm wide in the fourth millimetre from the tip. The author of this study did not know the exact data indicated in the literature on the taper of the RECIPROC blue R25 above the third millimetre from the tip, but its width in the fourth millimetre from the tip is certainly larger than 0.49 mm because that is the width of this file in the third millimetre from the tip. The research of Haïkel et al.,[24] Gambarini[25] and Plotino et al.[26] revealed that the increase of the cross-sectional area by the increase of the taper or the size of the file leads to the decrease in resistance to cyclic fatigue. Therefore, the comparison of two files of a similar build and heat treatment but different taper was not the purpose of this research.

There was no significant difference in the mean lengths of the fractured fragments for all tested instruments. Each file fractured at around 4 mm from the tip, which means they were properly positioned in the artificial canal.

Resin blocks were used for the research in order to define the number of canals that could be prepared until the file fractured. Research on extracted teeth would have a higher clinical value. However, it would be difficult or even impossible to find canals which have the same repetitive anatomy. In resin blocks, the canals are identical, having the same length, width, taper, degree and radius of curvature. As a result, the files were used in the same conditions. Of course, the material of resin blocks does not have the same mechanical properties as those of root dentine. The Knoop hardness of resin blocks is lower than that of dentine surrounding the pulp chamber of a tooth (22 kg/mm^2 and 30 kg/mm^2, respectively).[27,28] Therefore, the results achieved in resin blocks cannot be directly transferred to clinical work. The number of canals prepared in resin blocks for each file in this research cannot be considered a safe number of canals that may be prepared with these files *in vivo*.


8

Fig. 8: First line (RECIPROC blue R25, continuous rotation): six blocks prepared without fracture, and the file fractured inside the seventh block. Second line (RECIPROC blue R25, reciprocation): eight blocks prepared without fracture, and the file fractured inside the ninth block. Third line (Endostar E3 Azure 25/.06, continuous rotation): nine blocks prepared without fracture, and the file fractured inside the tenth block. Fourth line (Endostar E3 Azure 25/.06, OTR reciprocation): thirteen blocks prepared without fracture, and the file fractured inside the fourteenth block.

The research for this article consisted of two parts: cyclic fatigue resistance testing and resin block preparation. The aim was to check the influence of reciprocal motion on the lifespan of files both in the fatigue test and in the conditions in which the file works in curved canals and undergoes torsional strain resulting from canal widening (resin block test), which simulated the conditions in which a file works during an endodontic treatment. In a systematic review of *in vitro* studies by Ahn et al.,[15] it was found that, in most studies, reciprocal motion increases a file's resistance to fatigue in comparison with continuous rotation. There are very few studies which have investigated the influence of reciprocal motion on the lifespan of files which, at the same time, are affected by a fatigue mechanism and torsional stress. The results of this research show that using reciprocal motion during preparation of the canals decreases the risk of a file fracturing in a canal (Fig. 8).

In the present study, OTR motion was investigated because it is a new motion in endodontics and there is very little research on the influence of this motion on cyclic fatigue.[29,30] There has been no research on the influence of OTR motion on file fracture during canal preparation until now. Based on the present study, reciprocation of OTR motion prolongs the time to fracture and enables preparation of a larger number of canals before fracture.

Conclusion

Within the limitations of this study, both reciprocal motions (the one dedicated to RECIPROC files and OTR motion) significantly increased resistance to cyclic fatigue of the tested files compared with continuous rotation. Also, the number of canals in resin blocks prepared until file fracture significantly increased with the use of the two reciprocal motions.

Editorial note: A list of references is available from the publisher.

about

Dr Sławomir Gabryś graduated with a DDS from the Jagiellonian University School of Medicine in Cracow in Poland. He is a member of the Polskie Towarzystwo Endodontyczne (Polish association of endodontics) and the European Society of Endodontology and a core member of the Dental Masters Group. Since 2011, he has cooperated with the research department of Polskie Towarzystwo Endodontyczne. For eight years, with Poldent, he has conducted the postgraduate endodontic programme Endo Akademia.