Assessment of Fatigue Failure of Endodontic Instruments

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Abstract

This article discusses the features of fatigue fracture of dental instruments used in endodontics. Fatigue tests were carried out on machine endodontic files under axial rotation with a radius R = 0.5 mm and a bend length L = 5, 10 and 15 mm.

Common to all types of studied instruments was the maximum number of cycles, which was achieved with the smallest bend angle of 22.5 ° and a bend length of L = 5 mm.

The analysis showed that cyclic durability increases with decreasing length and bending angle of the endodontic instrument.

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Introduction

Successful endodontic treatment is realized by high-quality root canal treatment, which includes root canal cleaning and the further shaping of root canal. Tools designed for the passage and expansion of channels are collectively called “files” or “rimers”. They are mainly made of stainless austenitic steel or, as of recent times, of titanium nickelide (NiTi).

At each stage of the work, the dentist needs to preserve the natural anatomical configuration of the root canal, which is difficult to implement in the case of a large radius of curvature. The result is poor-quality channel processing, and in the most difficult cases, a tool breaks down, which is poorly predicted and, as a rule, occurs unexpectedly.[1, 2] As a result, the patient has to treat the affected tissue[3], or, in the worst case, switch to surgical processes[4].

One of the main causes of tool breakage during its operation in the channel is cyclic overload.[5] The cause of fatigue cracks is plastic microstrains that cannot be detected with the naked eye, as they occur in microvolumes of metal commensurate with the size of the elements of the crystal lattice. Under the influence of uneven repeated loads, the indicated microvolumes of the metal undergo repeated plastic deformation, as a result of which they are damaged.[6]

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The ability to withstand cyclic loading is determined by the elastic properties of the metal. Therefore, stainless steel can experience quite large loads, practically without deformation, as evidenced by the effective operation of steel tools indirect channels. Sufficient thickness (after size, according to ISO, -50) allows you to rotate such files with virtually no fear.[7] However, steel within elasticity withstands relative tension of about 1%, within irreversible deformations up to 1.5%, and then collapses. Therefore, steel tools with increasing size, as a rule, do not withstand cyclic loads, especially in curved channels.[8]

Instruments made from NiTi have some unique properties: superelasticity and shape memory. These properties are a consequence of the ability of the alloy to change its crystalline structure upon application of a mechanical load.[9] The threshold of loss of elastic properties by the alloy is 5 times lower than that of steel. The maximum relative stretching in the martensitic phase can reach 6%.[8]

One of the essential factors contributing to the occurrence of fatigue fracture[9,10] is the conical design of nickel-titanium tools, which leads to the concentration of torsion load within one rather small section of the tool. Moreover, the higher the taper, the higher the concentration of the torsion load. This phenomenon is due to the peculiarities of the distribution of the twist angle in the conical rod. Most often, the appearance of a crack and further destruction occurs at the tip of the working part of the tool [6,11,12], since the largest angle of twisting falls on it. Fatigue resistance may depend on the type of movement of the endodontic instrument in the root canal cavity [13-16]. The smallest resistance to fatigue failure was revealed[14] with continuous torsion, and the largest was found with a reverse torque of 90 °. This is due to the different stress distribution: with continuous torsion, they concentrate at one point, which leads to faster fatigue failure, and with combined rotation, stresses are distributed around the file circumference and are less dangerous.

The probability of destruction of the endodontic instrument should be assessed using a number of parameters of both the instrument itself (material and its mechanical properties, maximum permissible loads and deformations, taper, type and shape of the file), and parameters characterizing the dental canal, of which the most important are 17 radius of curvature and bending angle of the channel.

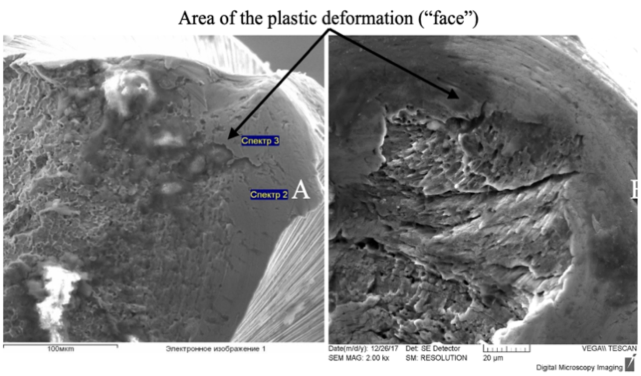


Figure 1. Electronic image of a fracture of a tool made of titanium nickelide (a) and steel 12X18H10 (b), indicating the areas of plastic deformation.

On the other hand, a frequent cause of tool destruction in the tooth canal is a decreased tactile perception, especially when the dentist uses machine tools. Our fractographic studies showed (Fig. 1) That the surface fractures of machine files made of stainless steel and titanium nickelide have extensive areas of significant plastic deformation. Such “problems” occur when the dentist tries to work, exerting axial pressure on a fixed fragment of an already broken instrument.

Thus, even the best combination of properties does not exclude the possibility of sudden destruction and therefore requires normalization of the operating time of each type of tool, and possibly each individual batch.

Materials and methods

In this study, new endodontic machine files made of titanium nickelide were used. Nickel-titanium alloy has a low modulus of elasticity, which gives the instruments good flexibility.

Fatigue tests were carried out using the original setup shown in Fig. 2. The principle of operation of the device is based on measuring the number of cycles of the endodontic instrument to failure at different bending angles. The file is fixed and its working part is set to a certain angle. The working part is placed in a quartz tube, which serves as an analog of the root canal. The installation allows testing under axial rotation with a speed of not more than 200 rpm, from positive to negative angles.

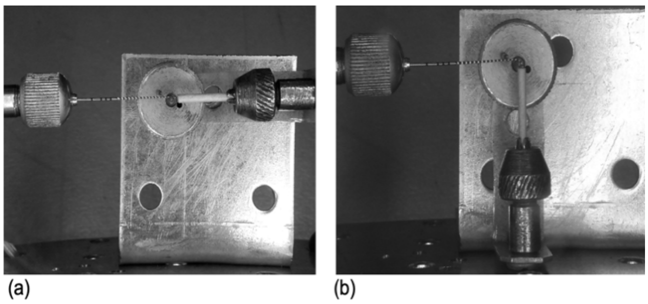


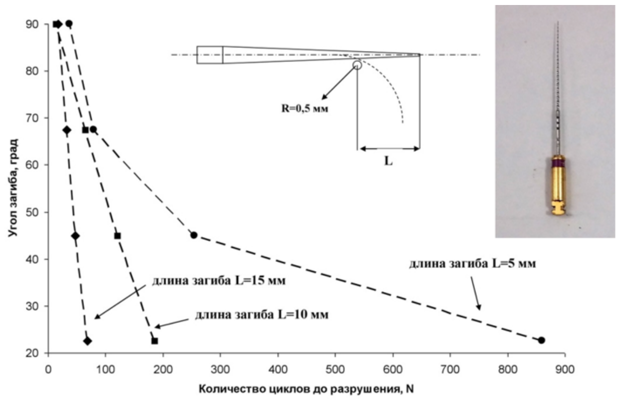
Figure 2. A fragment of the test setup – the initial position of the sample (a), the bend of the sample at an angle of 90° (b).

The test was carried out under the condition of bending the samples relative to the axis with a radius R = 0.5 mm at various angles and bending lengths L = 5, 10 and 15 mm.

Fractographic studies were performed using a TESCAN VEGA II LMH scanning electron microscope (SEM) with an operating voltage of 2 to 30 kV.

Results

As a result of the tests, the number of cycles to failure was obtained, which the sample withstood at certain angle and bend length. These data are presented in Fig. 3 in the form of cyclic durability curves constructed by analogy with the Weler curve. As can be seen, the greatest resistance to fatigue was exerted by the samples with the shortest bend length L = 5 mm.



Угол загиба, град	*Bending angle, degree*
Количество циклов до разрушения, N	*The number of cycles to failure, N*
Длина загиба	*Bending length*
мм	*mm*

Figure 3. Cyclic durability curves of endodontic files.

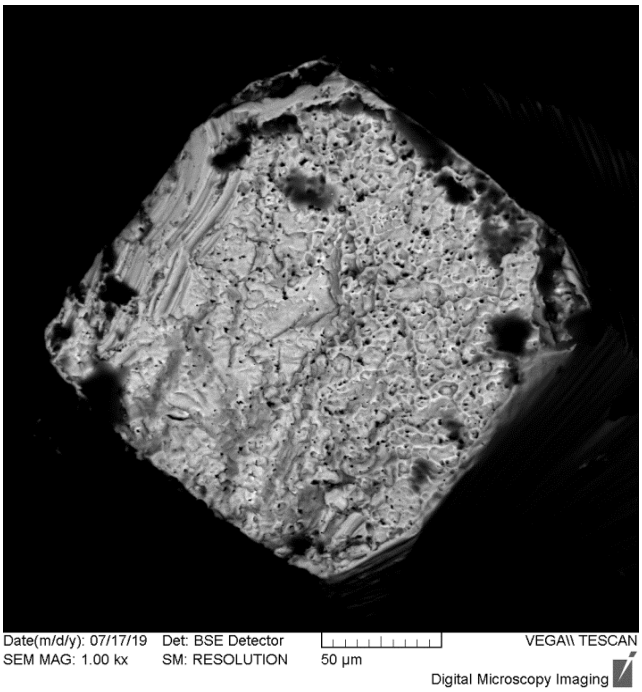
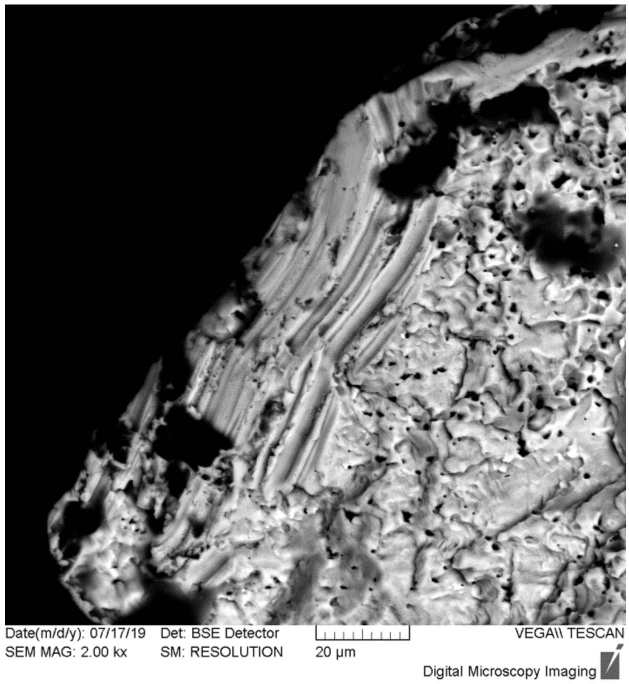
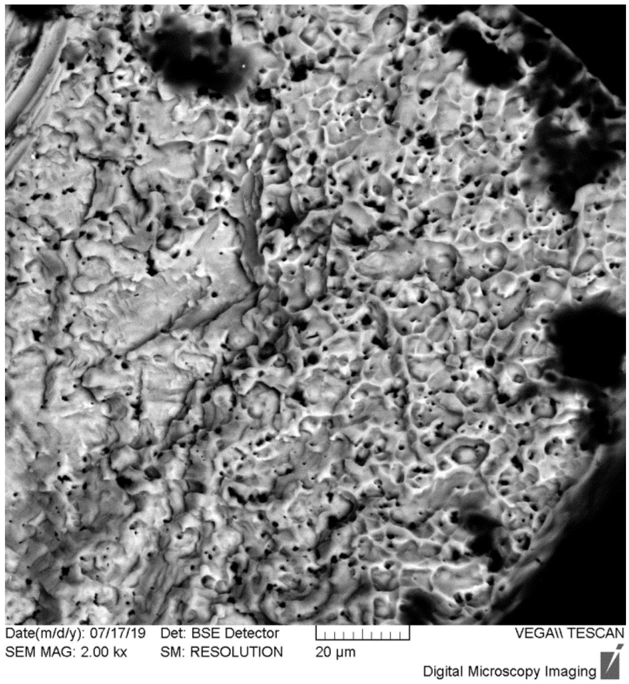


Figure 4. General view of the fracture photomicrograph of a fracture of the endodontic instrument at magnification ×1000.

Discussion



a



b

Figure 5. The fracture photomicrograph of a fracture of an endodontic instrument at a magnification of ×2000: dolomite zone (a), fatigue crack nucleation zone (b).

The data obtained do not fully agree with the studies presented in the review, this can be attributed to the fact that the root canal analog and instrument bends were selected to obtain general information on how the instrument behaves. More detailed test conditions, as in[14-15, 18-19], as well as the determination of stresses arising in the material or the construction of a process model[20, 21], will allow us to obtain a different result.

The fractogram of the general view of the fracture is shown in Fig. 4, as can be seen, the kink has two fracture zones. The first (Fig. 5b) is a zone of nucleation and propagation of a fatigue crack, and the second (Fig. 5a) is a zone of a dolom.

Conclusions

As part of the study, an original installation for fatigue testing of a dental instrument was designed and manufactured. It was found that files made of titanium nickelide have greater cyclic stability than tools made of stainless steel. In addition, during the tests, it was revealed that the maximum number of cycles to failure is achieved with the smallest value of the length and angle of the bending of the tool.

Declaration of Interest

The authors report no conflict of interest.

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