https://doi.org/10.36377/ET-0065

Experimental study of cyclic fatigue of nickel-titanium rotating endodontic instruments with controlled shape memory TC-Files Gold STEA (Videya)

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Abstract

INTRODUCTION. The dental market is constantly being replenished with new endodontic rotary instruments. Particular interest is drawn to the safety of using rotary files made in China from new nickel-titanium alloys with controlled memory wire (CM-Wire), which have undergone special treatment to enhance their elasticity and breakage resistance.

AIM. Experimental evaluation of the cyclic fatigue resistance of new endodontic rotary instruments TC-Files Gold STEA (manufactured by VIDEYA, China), made from CM-Wire alloy, using models that simulate root canals of varying anatomical complexity depending on the angle of curvature and radius of root curvature.

MATERIALS AND METHODS. Original models (patent application No. 2026183756) were used for testing, simulating three types of root canal curvatures: 45°, 90°, and an S-shaped curvature (450 and 600) with root curvature radii of 5 mm and 7 mm, respectively, and 5 mm and 3 mm for the S-shaped curvature. Nickel-titanium TC-files Gold STEA instruments of sizes 20/02, 15/03, 20/04, 25/04, 25/06, 30/04, 30/06, and 35/04 were sequentially fixed in the Geosoft Endoest endomotor. A total of 240 files were tested in the experiment, with 30 instruments of each size tested until breakage. The following parameters were set on the endomotor for all instruments: rotation speed of 250 RPM and torque of 3 N·cm. The files were inserted into a groove of the corresponding size, the endomotor was turned on, and the time until the instrument broke was recorded. The average time to breakage was calculated for each instrument size. Using a caliper, the length of the broken piece of each instrument was measured, and the average breakage length for each instrument size was determined. The number of cycles to breakage was also calculated. Statistical analysis of the obtained results was performed using multifactorial ANOVA in Statistica 13 software.

RESULTS. The highest resistance to cyclic loads in the root canal models with a 45° curvature and a 5 mm radius of curvature was demonstrated by TC-files Gold STEA size 20/04. In the root canal models with a 90° curvature and a 7 mm radius of curvature, as well as with an S-shaped curvature at angles of 45° and 60° and radii of curvature of 5 mm and 3 mm, respectively, the TC-files Gold STEA size 15/03 showed the greatest resistance. The lowest resistance to cyclic loads in the root canal models with a 45° curvature and a 5 mm radius of curvature was observed in TC-files Gold STEA size 35/04. In the models with a 90° curvature and a 7 mm radius of curvature, the least resistance was found in TC-files Gold STEA size 30/06, while in the models with an S-shaped curvature at angles of 45° and 60° and radii of curvature of 5 mm and 3 mm, respectively, the least resistance was shown by TC-files Gold STEA size 30/04. For all instrument sizes, breakage occurred most quickly when rotating in S-shaped canals. For six of the eight sizes (TC-files Gold STEA sizes 20/02, 15/03, 25/04, 25/06, 30/04, and 35/04) produced by Videya, cyclic fatigue accumulated faster when the instruments were rotated in root canal models with a 45° curvature and a 5 mm radius of curvature, compared to the models with a 90° curvature and a 7 mm radius of curvature.

CONCLUSIONS. The resistance of files made from CM-Wire alloys to cyclic fatigue depends on the size, taper, design of the instrument, and the anatomical complexity of the root canal. The risk of instrument breakage is highest in S-shaped root canal curvatures. In S-shaped canals (curvature of 45° with a radius of 5 mm and curvature of 60° with a radius of 3 mm), TC-files Gold STEA instruments with .04 and .06 tapers are not recommended. A root curvature of 45° with a 5 mm radius may be more dangerous for most sizes of CM-Wire alloy instruments than a 90° canal curvature with a 7 mm radius. Therefore, when diagnosing the complexity of root canal anatomy, both the angle of the root canal curvature and the radius of the curvature should be taken into account.

Keywords: rotary endodontic instruments, Ni-Ti files, TC-files Gold STEA, TC-files, STEA, VIDEYA, CM-Wire, cyclic fatigue, instrument fracture

Article info: received – 23.11.2024; revised –10.01.2025; accepted – 12.01.2025

Conflict of interest: The authors report no conflict of interest.

Acknowledgements: There are no funding and individual acknowledgments to declare.

For citation: Tairov V.V., Adamchik A.A., Mendosa E.Yu., Mamedova L.A., Filippova M.D., Dorogan V.V., Savina M.V. Experimental study of cyclic fatigue of nickel-titanium rotating endodontic instruments with controlled shape memory TC-Files Gold STEA (Videya). *Endodontics Today.* 2025;23(1):5–14. https://doi.org/10.36377/ET-0065

Экспериментальное исследование циклической усталости никель-титановых вращающихся эндодонтических инструментов с контролируемой памятью формы TC-Files Gold STEA (Videya)

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Резюме

ВВЕДЕНИЕ. Стоматологический рынок постоянно пополняется новыми эндодонтическими машинными инструментами. Особый интерес вызывает безопасность использования ротационных файлов, изготовленных в Китае из новых никель-титановых сплавов с контролируемой памятью формы CM-Wire, подвергшихся специальной обработке, увеличивающей их эластичность и устойчивость к поломкам.

ЦЕЛЬ ИССЛЕДОВАНИЯ. Экспериментальная оценка устойчивости к циклической усталости новых эндодонтических ротационных инструментов TC-Files Gold STEA (производства VIDEYA, Китай), изготовленных из сплава CM-Wire, с использованием моделей, имитирующих корневые каналы различной анатомической сложности в зависимости от угла изгиба и радиуса кривизны корня зуба.

МАТЕРИАЛЫ И МЕТОДЫ. Для проведения испытаний использовались оригинальные модели (заявка на патент № 2026183756), имитирующие три вида изгибов каналов корней зубов: 45°, 90°, а также S-образный изгиб (45° и 60°) и радиусами кривизны корней соответственно – 5 и 7 мм, для S-образного изгиба – 5 и 3 мм. Никель-титановые инструменты TC-files Gold STEA размеров 20/02, 15/03, 20/04. 25/04, 25/06, 30/04, 30/06, 35/04 поочередно фиксировались в эндомотор Geosoft Endoest. Всего в эксперименте были протестированы 240 файлов, по 30 инструментов каждого размера исследовали до поломки. Для всех инструментов на эндомоторе устанавливались следующие параметры: скорость вращения 250 оборотов в минуту и значение торка 3 Н/см, файлы погружали в канавку соответствующего размера, включали эндомотор и засекали время до поломки инструмента. Для каждого инструмента каждого размера вычисляли среднее значение времени до поломки. При помощи штангенциркуля, измеряли длину отломка каждого инструмента и вычисляли среднее значение длины отломка для инструмента каждого размера. Рассчитывали число циклов до поломки. Статистический анализ полученных результатов проводили путем многофакторного дисперсионного анализа ANOVA в программе Statistica 13.

РЕЗУЛЬТАТЫ. Наибольшую устойчивость к циклическим нагрузкам в каналах моделей с изгибом 45° и радиусом кривизны 5 мм продемонстрировали TC-files Gold STEA размера 20/04, в каналах моделей с изгибом 90° и радиусом кривизны 7 мм, а также с S-образным изгибом с углами 45°, 60° и радиусами кривизны 5 мм, 3 мм соответственно – TC-files Gold STEA размера 15/03. Наименьшую устойчивость к циклическим нагрузкам в каналах моделей с изгибом 45° и радиусом кривизны 5 мм показали TC-files Gold STEA размера 35/04, в каналах моделей с изгибом 90° и 7 мм радиусом кривизны – инструменты TC-files Gold STEA размера 30/06, в каналах моделей с S-образным изгибом с углами 45°, 60° и радиусами кривизны 5 мм, 3 мм соответственно – TC-files Gold STEA размера 30/04. Для всех размеров инструментов поломки быстрее всего наступали при их вращении в S-образных каналах. Для инструментов шести размеров (TC-files Gold STEA размеров 20/02, 15/03, 25/04, 25/06, 30/04, 35/04) из представленных восьми размеров, выпускаемых производителем Videya, циклическая усталость накапливалась быстрее при вращении инструментов в каналах моделей с изгибом 45° и радиусом кривизны 5 мм в сравнении с каналами моделей с изгибом 90° с 7 мм радиусом кривизны.

ВЫВОДЫ. Устойчивость файлов из CM-Wire сплавов к циклической усталости зависит от размера, конусности, дизайна инструмента и от сложности анатомических условий канала корня. Риск поломки инструмента максимален при S-образной форме изгиба корневого канала. В каналах с S-образным изгибом (кривизна 45° с радиусом 5 мм и кривизна 60° с радиусом кривизны 3 мм) инструменты TC-files Gold STEA .04 и .06 конусности применять не рекомендуется. Изгиб корня в 45° с радиусом кривизны 5 мм может быть для большинства размеров инструментов из сплава CM-Wire опаснее, чем изгиб канала 90° с радиусом кривизны 7 мм. Следовательно, при диагностике сложности анатомии корневого канала, следует учитывать, как угол изгиба корневого канала зуба, так и радиус кривизны корневого канала.

Ключевые слова: ротационные эндодонтические инструменты, никель-титановые инструменты, TC-files Gold STEA, TC-files, STEA, VIDEYA, никель-титановый сплав с контролируемой памятью формы, циклическая усталость, поломка инструментов

Информация о статье: поступила – 23.11.2024; исправлена – 10.01.2025; принята – 12.01.2025

Конфликт интересов: авторы сообщают об отсутствии конфликта интересов.

Благодарности: финансирование и индивидуальные благодарности для декларирования отсутствуют

Для цитирования: Таиров В.В., Адамчик А.А., Мендоса Е.Ю., Мамедова Л.А., Филиппова М.Д., Дорогань В.В., Савина М.В. Экспериментальное исследование циклической усталости никель-титановых вращающихся эндодонтических инструментов с контролируемой памятью формы TC-Files Gold STEA (Videya). *Эндодонтия Today.* 2025;23(1):5–14. https://doi.org/10.36377/ET-0065

INTRODUCTION

The outcome of endodontic treatment directly depends on the thorough isolation of the operative field, the adequacy of root canal instrumentation, effective irrigation (taking into account the activity of irrigants, the sequence of solution application protocols, their sufficient exposure, and activation in each canal), adherence to aseptic conditions during canal drying, the application of sealers and fillers, the quality of canal obturation, and the hermeticity of the post-endodontic restoration [1; 2]. Modern endodontic practice prioritizes the use of machine-driven nickel-titanium (NiTi) instruments for mechanical canal preparation. Their use significantly accelerates treatment and ensures higher quality outcomes [3; 4]. Machine-driven NiTi instruments are constantly evolving, with changes in alloy processing resulting in improved mechanical properties. These instruments are becoming more flexible and resistant to stress. However, improper technique, delayed disposal of worn instruments, or working in severely curved canals may result in instrument fracture [5–7].

Instrument fractures often worsen the prognosis of treatment since the retrieval of fragments is associated with numerous challenges, such as excessive thinning of root dentin, the risk of strip perforation, overheating during prolonged ultrasonic tip contact with canal walls, and the need for specialized skills. Retrieval is not always successful. Instrument fragments hinder both mechanical and chemical canal preparation [8; 9].

The main causes of rotary endodontic instrument fractures are torsional overload (which occurs when an instrument binds in the canal and the torque exceeds the file's strength) and cyclic fatigue accumulation due to alternating compression and tension while rotating in a curved canal [10; 11]. Therefore, it is essential to preassess the anatomical features of the canal. In canals with pronounced curvature and a small radius, instruments made from the latest martensitic alloys, which possess controlled shape memory and enhanced elasticity, should be used only once.

The shape memory effect of NiTi alloys is the ability to recover their original shape upon heating above the transformation temperature. This property is inherent to all NiTi alloys, but the transition temperature from the martensitic (elastic, deformed) state to the austenitic (rigid, original) state of the crystal lattice depends on the alloy's composition and additional processing. This temperature can range from –20°C to 110°C.

Standard "silver" austenitic NiTi files have low-temperature martensitic transformation indicators (significantly below room temperature). As a result, during clinical use, they exhibit rigid properties and may cause canal transportation. In contrast, "gold" NiTi M-Wire instruments undergo additional thermal treatment during manufacturing, raising the phase transformation threshold to approximately 40°C. This makes the alloy more elastic and resistant to breakage.

Special thermo-electrical processing of CM-Wire, which alters the phase composition of the martensitic NiTi alloy, was developed in 2010. The CM-Wire alloy undergoes sequential acid-mechanical, thermal, and non-contact electrocharging dielectric treatment, resulting in new properties [12; 13]. The surface of CM-Wire instruments is strengthened, enhancing their cutting efficiency and corrosion resistance. Furthermore, the transformation temperature from the martensitic (elastic) phase to the austenitic (superelastic) phase of NiTi is increased [14; 15].

When working in curved canals, CM-Wire instruments do not fully straighten, demonstrating controlled shape memory. This significantly increases their resistance to cyclic loads compared to conventional NiTi files, which are stiffer, and M-Wire instruments, where NiTi undergoes only thermal treatment [16; 17].

The constant introduction of new endodontic instruments to the dental market underscores the importance of studying their mechanical properties to identify optimal usage protocols, risks of fractures, and potential limitations [18]. Studies often emphasize that endodontic instruments experience the highest loads in significantly curved canals [19]. This study evaluated the cyclic fatigue resistance of new endodontic TC-Files Gold STEA instruments (manufactured by Videya, China) made from CM-Wire alloy, determining the dependence of cyclic fatigue accumulation on instrument size, taper, design, and root curvature with varying radii of curvature.

MATERIALS AND METHODS

The study on cyclic fatigue resistance was conducted for all sizes of the new endodontic rotary instruments made of CM-Wire alloy with controlled shape memory, TC-Files Gold STEA (manufactured by Videya, China), specifically: 20/02, 15/03, 20/04, 25/04, 25/06, 30/04, 30/06, and 35/04. A total of 240 files were tested in the experiment, with 30 instruments of each size. All TC-Files Gold STEA instruments have a constant taper and a safe tip. The 20/02 and 15/03 TC-Files Gold STEA instruments have a square cross-section, while the remaining TC-Files Gold STEA instruments with .04 and .06 tapers have a triangular cross-section, are well-centered, and can be used in curved canals.

For the experiment, specially designed models were developed to simulate root canal curvatures: a 45° curvature with a 5 mm radius, a 90° curvature with a 7 mm radius, and an S-shaped curvature with angles of 45° and a 5 mm radius, and 60° and a 3 mm radius of root canal curvature. The models were made of metal and included a series of individual grooves, each 16 mm long, mimicking the lumen of a root canal (patent application No. 2026183756). The groove sizes corresponded to each of the tested rotary nickel-titanium endodontic instruments TC-Files Gold STEA in the following sizes: 20/02, 15/03, 20/04, 25/04, 25/06, 30/04, 30/06, and 35/04, respectively (Fig. 1).

The instruments of each size were sequentially fixed in the handpiece of a Geosoft Endoest endomotor, inserted into the corresponding canal of the model, and the model and endomotor were secured in a fixture. The endomotor was set to a rotation speed of 250 revolutions per minute and a torque of 3.0 N·cm for all instruments. The endomotor was activated, and the time to instrument fracture was recorded. Ten instruments of each size were tested to failure in models simulating root canal curvatures: (1) 45° curvature with a 5 mm radius, (2) 90° curvature with a 7 mm radius, and (3) S-shaped curvatures of 45° and 60° with radii of 5 mm and 3 mm, respectively. For each instrument size, the average time to fracture was calculated.

Using a caliper, the length of the fractured fragment was measured. The average fragment length was calculated for each instrument size.

The rotation and fracture process was recorded on video using an iPhone 14 Pro smartphone camera. To analyze the fracture level of the instrument within the root canal, a still frame was extracted at the moment of fracture from the video recording (Fig. 2–4).

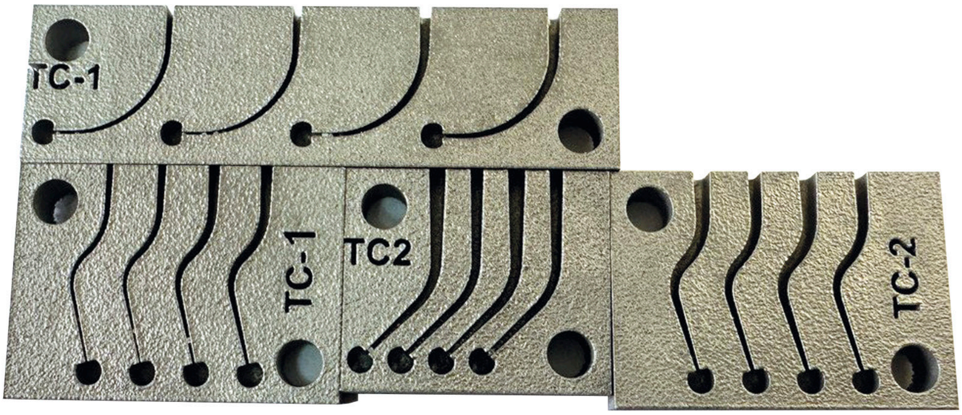

Fig. 1. Models for cyclic fatigue testing

Рис. 1. Модели для исследования циклической усталости

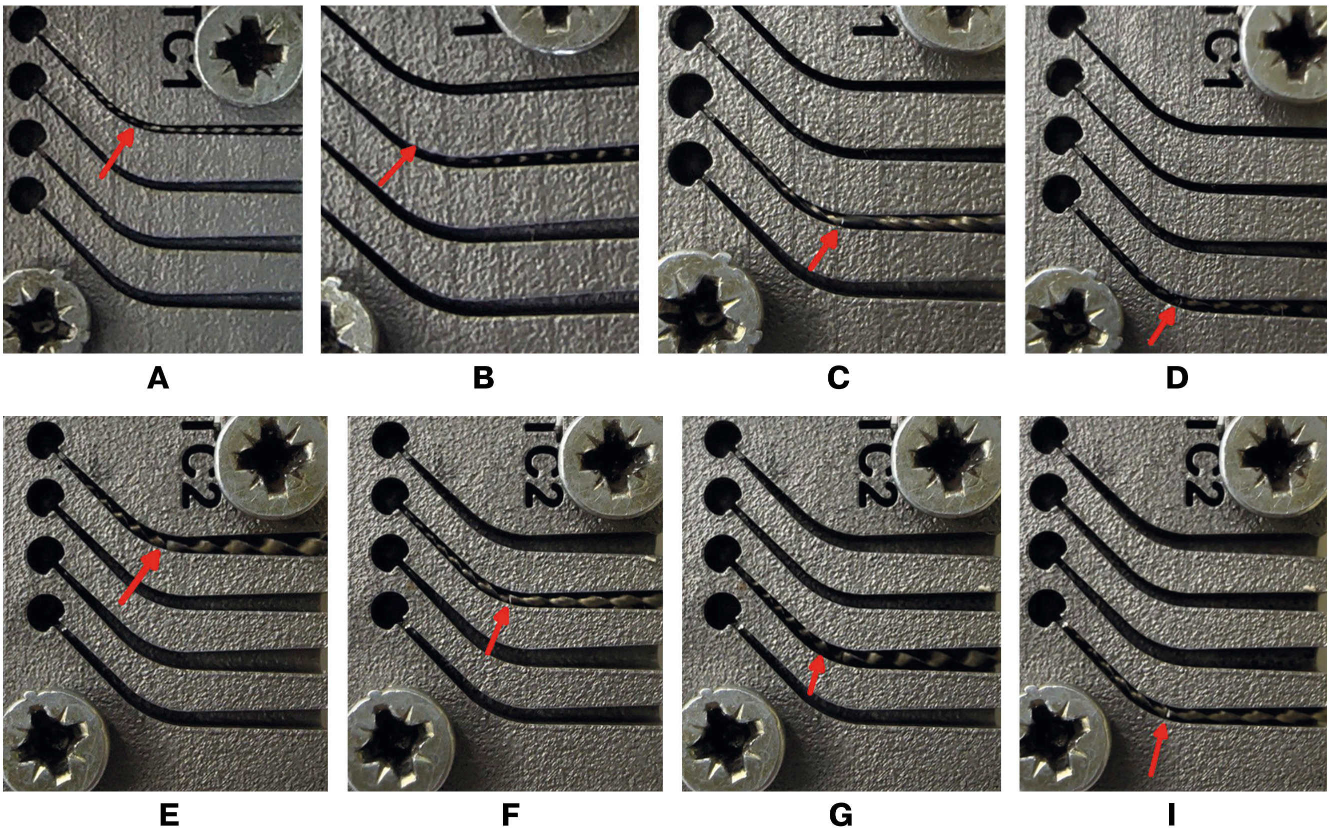

Fig. 2. Breakage level in the root canal model with a 45° curvature and a 5 mm radius of curvature:
A – TC-file 20/02; *B* – TC-file 15/03; *C* – TC-file 20/04; *D* – TC-file 25/04; *E* – TC-file 25/06; *F* – TC-file 30/04; *G* – TC-file 30/06; *I* – TC-file 35/04

Рис. 2. Уровень перелома инструмента в канале модели с изгибом 45° и радиусом кривизны 5 мм:
A – TC-file 20/02; *B* – TC-file 15/03; *C* – TC-file 20/04; *D* – TC-file 25/04; *E* – TC-file 25/06; *F* – TC-file 30/04; *G* – TC-file 30/06; *I* – TC-file 35/04

The calculation of the total number of complete motion cycles was performed using the formula:

$$N(\text{cycles}) = S \times t,$$

where *N(*cycles*)* – the number of complete cycles; *S* – the rotation speed; *t* – the time.

Statistical analysis of the obtained results was conducted using multifactorial analysis of variance (ANOVA) in the Statistica 13 software.

RESULTS AND DISCUSSION

The study of the cyclic fatigue of TC-Files Gold STEA (manufactured by Videya, China) using the developed models simulating root curvatures of 45° with a 5 mm radius, 90° with a 7 mm radius, as well as S-shaped curvatures of 45° and 60° with radii of 5 mm and 3 mm, respectively, was conducted using a fixture-mounted endomotor handpiece. The following results were obtained.

Video recordings captured the moments of instrument fracture, with still frames extracted at the fracture points. The location of the fracture is indicated by an arrow in the images.

The analysis of the extracted still frames revealed the fracture levels of the instruments.

In the cyclic fatigue tests conducted with the root canal model featuring a 45° curvature and a 5 mm radius, all tested TC-Files Gold STEA instruments (20/02, 15/03, 20/04, 25/04, 25/06, 30/04, 30/06, and 35/04) exhibited fractures with fragment lengths of approximately equal size, occurring in the area of maximum curvature.

In the tests using the S-shaped root canal model with curvatures of 45° and 60° and radii of 5 mm and 3 mm, respectively, all tested TC-Files Gold STEA instruments (20/02, 15/03, 20/04, 25/04, 25/06, 30/04, 30/06, and 35/04) demonstrated fractures in the area of the second apical curvature. One instrument (25/06) fractured into three separate fragments.

In the tests conducted with the root canal model featuring a 90° curvature and a 7 mm radius, the TC-Files

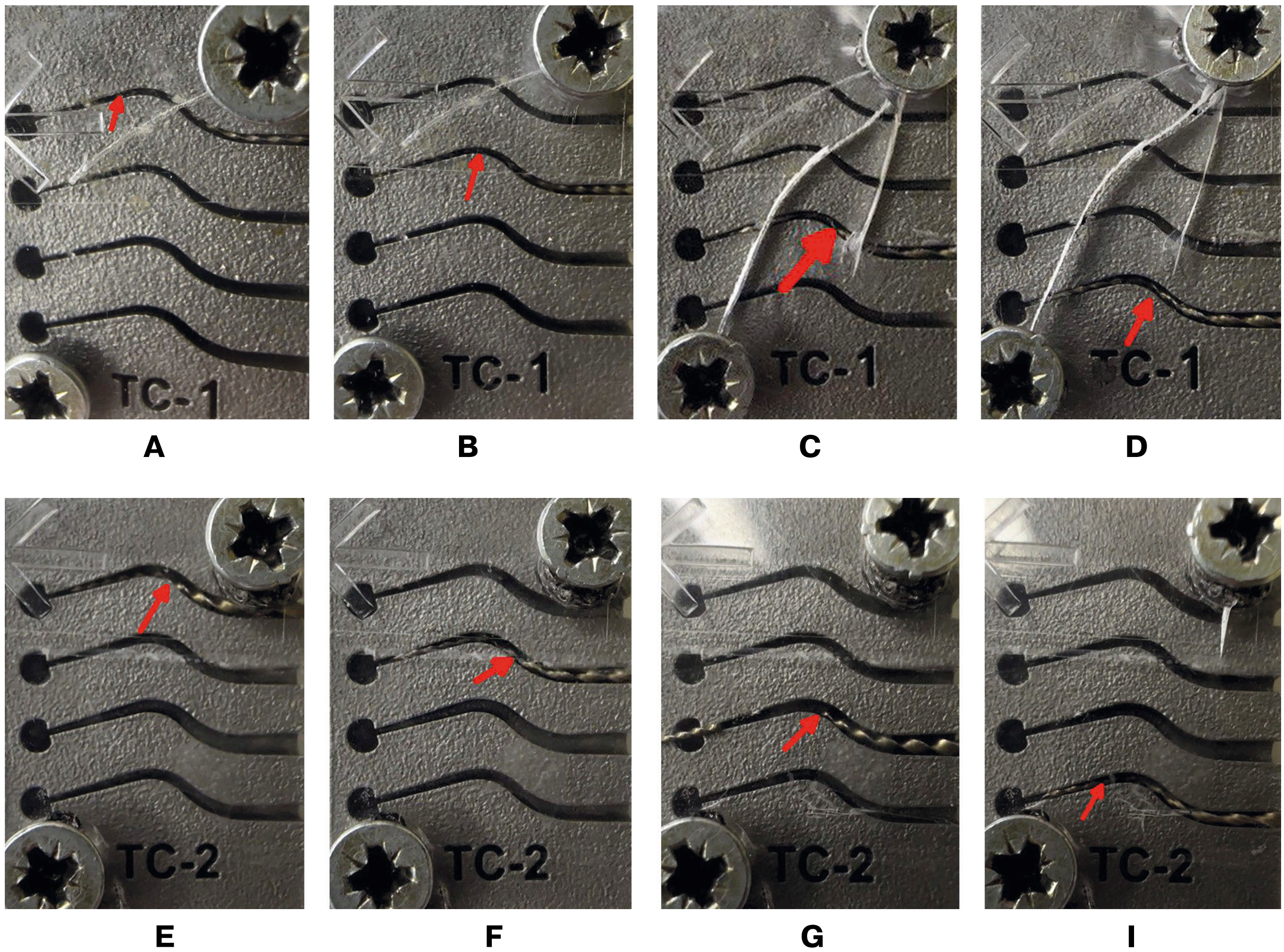

Fig. 3. Breakage level an S-shaped in the root canal model with a 45°, 60° curvature and a 5 mm, 3 mm radius of curvature: *A* – TC-file 20/02; *B* – TC-file 15/03; *C* – TC-file 20/04; *D* – TC-file 25/04; *E* – TC-file 25/06 (the instrument split into 3 fragments); *F* – TC-file 30/04; *G* – TC-file 30/06; *I* – TC-file 35/04

Рис. 3. Уровень перелома инструмента в S-образном канале с изгибами 45°, 60° и радиусами кривизны 5 мм, 3 мм соответственно: *A* – TC-file 20/02; *B* – TC-file 15/03; *C* – TC-file 20/04; *D* – TC-file 25/04; *E* – TC-file 25/06 (инструмент раскололся на 3 фрагмента); *F* – TC-file 30/04; *G* – TC-file 30/06; *I* – TC-file 35/04

Gold STEA instruments 20/02, 15/03, and 20/04 fractured in the apical portion at the point of maximum curvature (bend radius). The TC-Files Gold STEA instruments 25/04, 25/06, 30/04, 30/06, and 35/04 fractured in the coronal portion at the start of the curvature.

A cycle is defined as the complete set of movements of the instrument's segments and the instrument as a whole, starting from any arbitrarily chosen position and returning to its original position.

The number of cycles was calculated for each instrument in models with canals featuring a 45° curvature and a 5 mm radius, a 90° curvature and a 7 mm radius, and an S-shaped canal with curvatures of 45° and 60° and radii of 5 mm and 3 mm, respectively.

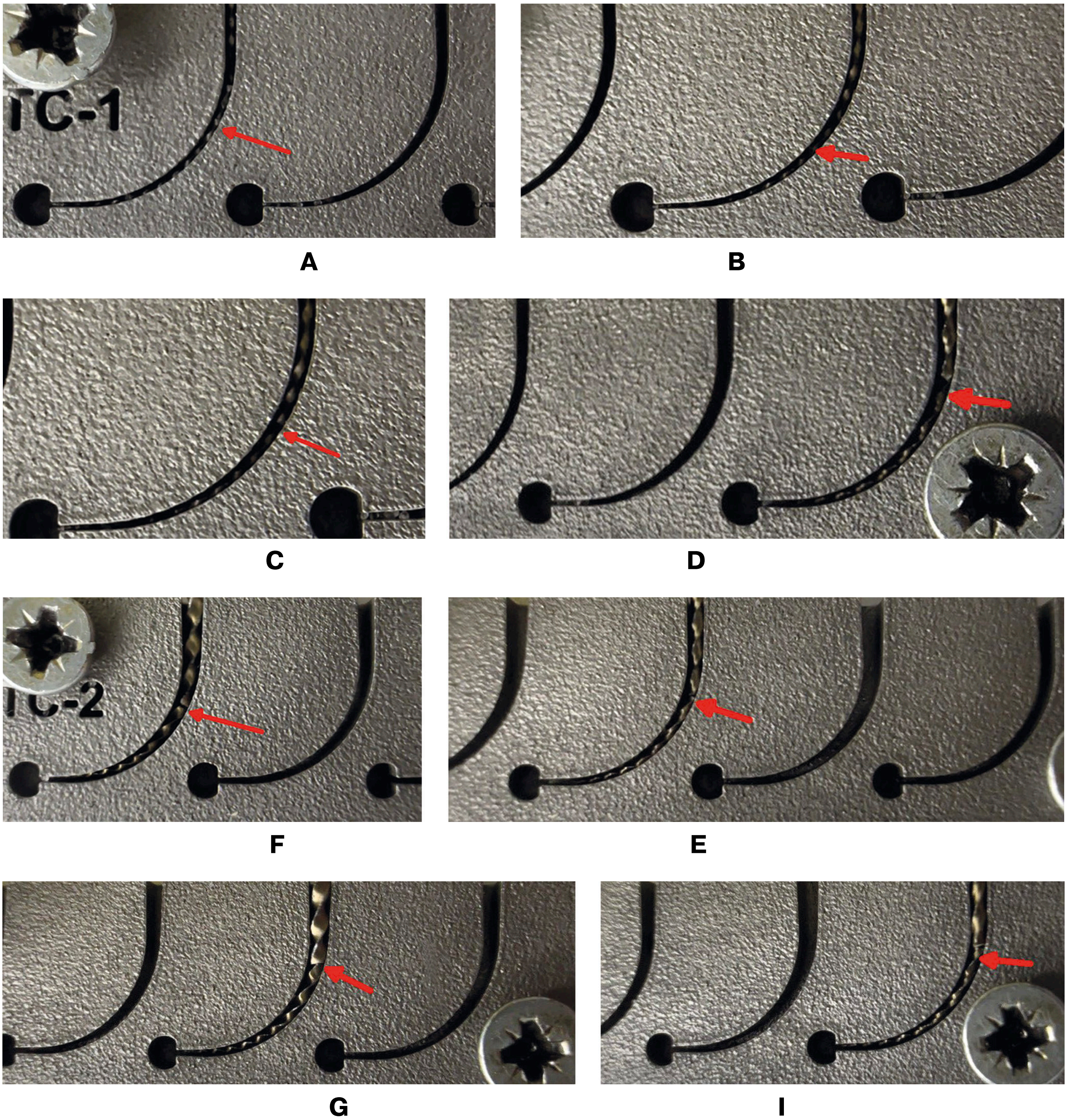

Fig. 4. Breakage level in the root canal model with a 90° curvature and a 7 mm radius of curvature:
A – TC-file 20/02; *B* – TC-file 15/03; *C* – TC-file 20/04; *D* – TC-file 25/04; *E* – TC-file 25/06; *F* – TC-file 30/04; *G* – TC-file 30/06; *I* – TC-file 35/04

Рис. 4. Уровень перелома инструмента в канале модели с изгибом 90° и радиусом кривизны 7 мм:
A – TC-file 20/02; *B* – TC-file 15/03; *C* – TC-file 20/04; *D* – TC-file 25/04; *E* – TC-file 25/06; *F* – TC-file 30/04; *G* – TC-file 30/06; *I* – TC-file 35/04

Table 1. Summary table of the results of the study of cyclic fatigue of instruments «TC-files (STEA)»
Таблица 1. Сводная таблица результатов исследования циклической усталости инструментов «TC-files (STEA)»

Instrument Size	Speed and Torque Parameters	Average Time to Instrument Fracture, sec	Average Fragment Length of the Instrument, mm
Canal with a 45° Curvature and a 5 mm Radius			
20/02	S=250, T=3.0	408±10	7,29±0,02
15/03	S=250, T=3.0	551±12	5,76±0,01
20/04	S=250, T=3.0	674±14	8,02±0,03
25/04	S=250, T=3.0	272±4	7,26±0,02
25/06	S=250, T=3.0	85±12	7,63±0,04
30/04	S=250, T=3.0	129±11	7,21±0,03
30/06	S=250, T=3.0	77±9	7,17±0,02
35/04	S=250, T=3.0	47±1	8,06±0,04
Canal with a 90° Curvature and a 7 mm Radius			
20/02	S=250, T=3.0	473±19	11,92±0,51
15/03	S=250, T=3.0	664±24	9,41±0,21
20/04	S=250, T=3.0	301±9	5,06±0,06
25/04	S=250, T=3.0	274±3	11,24±0,14
25/06	S=250, T=3.0	151±9	8,32±0,09
30/04	S=250, T=3.0	305±12	8,36±0,07
30/06	S=250, T=3.0	58±1	10,83±0,05
35/04	S=250, T=3.0	111±6	11,79±0,16
S-Shaped Canal with Curvatures of 45° and 60° and Radii of 5 mm and 3 mm			
20/02	S=250, T=3.0	61±6	8,11±0,03
15/03	S=250, T=3.0	62±8	8,73±0,02
20/04	S=250, T=3.0	7±1	7,58±0,04
25/04	S=250, T=3.0	4±1	6,87±0,05
25/06	S=250, T=3.0	6±1	9,09 ±0,08 1 the instrument fractured into three fragments (5,67+3,42)
30/04	S=250, T=3.0	3±1	5,32±0,12
30/06	S=250, T=3.0	6±1	4,41±0,15
35/04	S=250, T=3.0	4±1	6,44±0,36

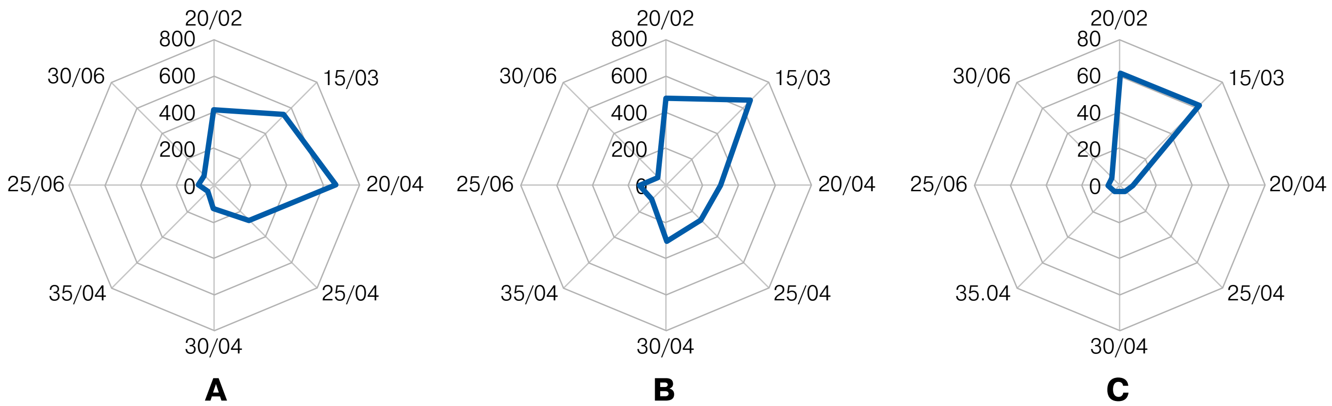

Fig. 26. Average time to fracture of each instrument size: *A* – in canal with a 45° curvature, sec; *B* – in canal with a 90° curvature, sec; *C* – in S-shaped canal with curvatures, sec

Рис. 5. Среднее время до перелома инструмента каждого размера: *A* – в канале с изгибом 45°, сек; *B* – в канале с изгибом 90°, сек; *C* – в канале с S-образным изгибом, сек

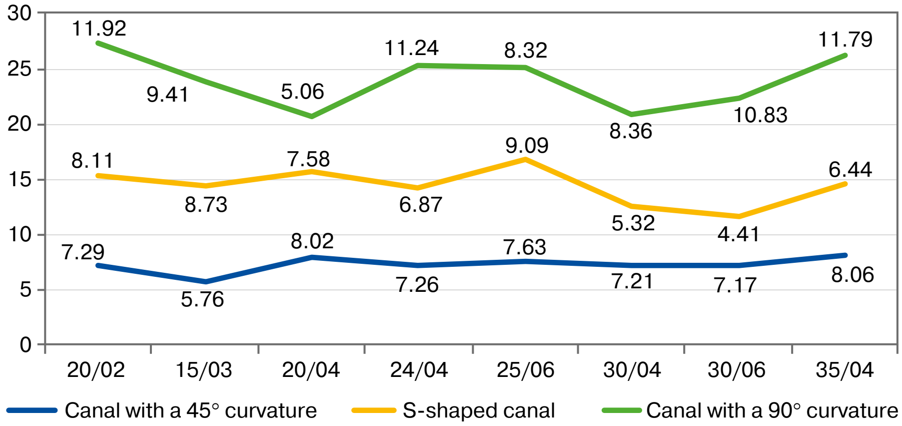

Fig. 6. The average length of tool fragments in channels of various types, mm

Рис. 6. Средняя длина отломков инструментов в каналах различных типов, мм

Table 2. The number of cycles of the instruments, according to the results of the study under root conditions in 45°, 90° and S-shaped

Таблица 2. Количество циклов у инструментов, по результатам исследования в условиях корней в 45°, 90°и S образного

Instrument	Number of Cycles		
	45°	90°	S-shaped
20/02	1700±6	1971±7	254±2
15/03	2295±9	2767±6	258±2
20/04	2808±9	1254±5	29±1
25/04	1133±4	1142±4	17±1
25/06	354±1	629±3	25±1
30/04	537±2	1271±6	13±1
30/06	320±1	242±1	25±1
35/04	196±1	462±2	17±1

Example calculation for the 20/02 “TC-Files (STEA)” instrument with a 45° angle:

$$N(\text{cycles}) = S \times t,$$

where the micromotor speed of 250 revolutions per minute was converted to revolutions per second: 250÷60=4.16666667 revolutions per second.

Thus, N(cycles) = 4.16666667 × 408 = 1700 cycles.

CONCLUSIONS

The cyclic fatigue resistance of CM-Wire alloy files depends on the instrument’s size, taper, design, and the anatomical complexity of the root canal. The risk of instrument fracture is highest in S-shaped root canal curvatures. It is not recommended to use TC-Files Gold STEA instruments with .04 and .06 tapers in such canals. A root curvature of 45° with a 5 mm radius of curvature may be more hazardous for most sizes of CM-Wire alloy instruments compared to a canal with a 90° curvature and a 7 mm radius of curvature. Therefore, when diagnosing the complexity of root canal anatomy, both the angle of the root canal curvature and the radius of curvature should be taken into account.

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