A Comparative Study of Cyclic Fatigue of 10 Different Types of Endodontic Instruments: an in Vitro Study

Komparativno istraživanje cikličkog zamora deset različitih vrsta endodontskih instrumenata: istraživanje in vitro

Introduction

The use of Nickel-Titanium (NiTi) instruments has increased due to the advantages they present compared to manual files (1-2), which are used in canal-shaping procedures to reduce bacteria levels and facilitate irrigation and obturation for long-term success (3, 4). Their main advantages are elasticity and cutting efficiency (5, 6), and also the frequent changes of characteristics and cross-section of endodontic files have increased their resistance to cyclic fatigue (7-9), but their major problem is fracturing in root canals (1, 2).

With regard to currents systems, new manufacturing processes and alloys such as CM-Wire, M-Wire and Gold-Wire have been developed to improve conventional NiTi in recent years (10). Another improvement has been a reciprocating motion, an oscillating motion that rotates the files in one direction then reverses their motion before effecting a complete rotation (11). The useful life of instruments can be increased by reciprocating motion, as it presents better resistance to cyclic fatigue than continuous rotation (12, 13). Frequency, apical strength of instrument, pressure applied by the operator and enlargement of canal are among the clinical factors that increase cyclic fatigue risk (12, 13).

Uvod

Uporaba instrumenta od nikal-titanijeve legure (Ni-Ti) je postala organizirana več kot ekstenzivna in novi postopki s učinkovitostjo in učinkovitostjo pri rezanju (5, 6), in s tem postanejo tudi v pregledni sistem izdelkov za zamašitev. Pripomene za učinkovite instrumente vključujejo zmoteno izgubljeno učinkovitost (7-9), vendar se je temeljna predmetna dejavnost v postopku rezanja v odgovornem kanalu (1, 2)

Ker je bil postopek rezanja v odgovornem kanal učinkovit v resničnem delu postopka (1, 2), so bile vendar izgubljene učinkovitost in reznotvoritvena vrednost izdelkov NiTi (7-9). Oprobnicki izid je izhajal od različnih faktorjev, vključno z frekvenco, apikalno vrednostjo in pripomočno napetostjo, ki se izvaja operaterom, kot tudi razpon za širjenje postopka v kanalu (1, 2).
which also affect the resistance of files to cyclic fatigue (14).

Science advances, and single-use instrumentation systems have been created to prevent fracture from overuse. The files are used in a single tooth, in 1 to 4 root canals (as in molars) and are safe in narrow and curved canals (15). However, several studies have suggested that their traction and compression strengths are a disadvantage in the case of continuous rotation instruments (16).

In relation to the assessment of the separated fragment lengths, it is preferable that the longest fragment should remain inside the tooth to make its removal easier.

Therefore, this study was designed to test the null hypothesis that there were no significant differences between size 25 files F360 (Komet Dental, Lemgo, Germany), F6 SkyTaper (Komet Dental, Lemgo, Germany), Hyflex EDM (Coltene, Altstätten, Switzerland), iRace (FKG Dentaire, La Chaux-de-Fonds, Switzerland), Neoniti (Neolix, Chartres-La Foret, France), One Shape (Micro-Mega, Besançon, France) Protaper Next (Dentsply Maillefer, Ballaigues, Switzerland), Reciproc (VDW, Munich, Germany), Revo-S (Micro-Mega, Besançon, France) and Wave One Gold (Dentsply Maillefer, Ballaigues, Switzerland) in terms of resistance to cyclic fatigue and separated fragment lengths.

Material and methods

New size 25 files of the systems studied were selected (n=30 per system, total 300). The systems were divided into groups in alphabetical order (Table 1).

The instruments were rotated using X-Smart Plus endo motor (Dentsply Maillefer, Ballaigues, Switzerland) (Fig. 1) at the speed and torque recommended by manufacturers. The speed and torque of each group using only the size 25 files of endodontic systems were:
Group 1 (F360): 300 rpm, 1.8 N·cm and continuous rotation.
Group 2 (F6 SkyTaper): 300 rpm, 2.2 N·cm and continuous rotation.
Group 3 (Hyflex EDM): 500 rpm, 2.5 N·cm and continuous rotation.
Group 4 (iRace): 600 rpm, 1.5 N·cm and continuous rotation.
Group 5 (Neoniti): 400 rpm, 1.5 N·cm and continuous rotation.
Group 6 (One Shape): 400 rpm, 4 N·cm and continuous rotation.
Group 7 (Protaper Next): 300 rpm, 2 N·cm and continuous rotation.
Group 8 (Reciproc): 300 rpm, 2 N·cm and reciprocation motion.
Group 9 (Revo-S): 350 rpm, 0.8 N·cm and continuous rotation.
Group 10 (Wave One Gold): 350 rpm, 2 N·cm and reciprocation motion.

The instruments were firmly held with clamping mechanism (Fig. 2) with passive adjustment and without pressure in a stainless-steel block containing an artificial canal with the following characteristics: 60° curvature, radius of curvature 3.5 mm, length 21 mm, width 2 mm, and depth 3 mm. The characteristics of model were similar to the block used by Gambarini et al. (17) and Champa et al. (18). The canal was lubricated with glycerin after each file.

The time was calculated in seconds (s) until fracture. The number of cycles to fracture (NCF) was calculated by the following formula: (Resistance (s) x Speed)/60. The separated fragment lengths were measured with a digital Vernier caliper (Fig. 3).

Statistical analysis was performed with the SPSS 18 programme at a 95% confidence level, using the Levene’s Test skupina 1 (F360): 300 rpm, 1,8 N cm i kontinuirana rotacija;
skupina 2 (F6 SkyTaper): 300 rpm, 2,2 N cm i kontinuirana rotacija;
skupina 3 (Hyflex EDM): 500 rpm, 2,5 N cm i kontinuirana rotacija;
skupina 4 (iRace): 600 rpm, 1,5 N cm i kontinuirana rotacija;
skupina 5 (Neoniti): 400 rpm, 1,5 N cm i kontinuirana rotacija;
skupina 6 (One Shape): 400 rpm, 4 N cm i kontinuirana rotacija;
skupina 7 (Protaper Next): 300 rpm, 2 N cm i kontinuirana rotacija;
skupina 8 (Reciproc): 300 rpm, 2 N cm i recipročni pokret;
skupina 9 (Revo-S): 350 rpm, 0,8 N cm i kontinuirana rotacija;
skupina 10 (Wave One Gold): 350 rpm, 2 N cm i recipročni pokret.

Instrumente je čvrsto držao škripac (slika 2.) s pasivnom prilagodbom i bez pritiska, na čeličnom bloku koji je imao umjetno napravljeni kanal sa sljedećim karakteristikama: zavoj od 60°, radijus zavoja 3,5 mm, duljina 21 mm, širina 2 mm i dubina 3 mm. Karakteristike modela bile su slične blokovima kojima su se koristili Gambarini i suradnici (17) te Champa i njegovi kolege (18). Kanal je vlažen glicerinom nakon svake iglice.

Vrijeme do puknuća mjereno je u sekundama (s). Broj ciklusa potreban da se dogodi puknuće (NCF) izračunat je sljedećim formulom: otpor (s) × brzina/60. Separirani, frakturirani fragmenti mjereni su Vernierovom digitalnom pomičnom mjerkom (slika 3.).

Statistička analiza obavljena je u programu SPSS 18 na 95-postotnom intervalu pouzdanosti s pomoću Levenova testa za usporedbu varijanci, Welchova testa za usporedbu srednjih vrijednosti te Games-Howellova testa za otkrivanje razlika između skupina.

Figure 1. Hyflex EDM 25/~ file in an artificial 60° canal.
Slika 1. Instrument Hyflex EDM veličine 25 u umjetnom kanalu sa zavojem od 60° canal.

Figure 2. Clamping mechanism of the handpiece for the X-Smart Plus endo motor.
Slika 2. Škripac s količnikom endodontskog mikromotora X-Smart Plus

Figure 3. Measurement of separated fragment of Wave One Gold Primary (25/0.07) file with digital Vernier caliper.
Slika 3. Mjerenje separiranog fragmenta instrumenta sustava Wave One Gold Primary (25/0,07) s pomoću Vernierove digitalne pomične mjerke
to compare variances, the Welch’s Test to compare means, and the Games-Howell’s Test to reveal differences between groups.

**Results**

In all of the comparisons that were made, the Levene’s Test was carried out, and no equal variances were assumed (P<0.05); therefore, it was decided to carry out the Welch’s Test (Tables 2, 3 and 4).

The cyclic fatigue mean values and statistics are presented in Table 2. Statistically, in terms of resistance, Neoniti and Hyflex EDM were superior to other systems (P<0.05), but there were no significant differences between Wave One and F6 SkyTaper (P = 1,000), sustava One Shape i Protaper Next (P = 0,121), su-

**Table 2.** Means and statistics for resistance to cyclic fatigue (s).

|            | F360      | F6        | Hyflex    | iRace     | Neoniti   | O.Shape   | P.Next    | Reciproc  | R-S       | WOG       |
|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Mean       | 152.43±   | 190.83±   | 331.07±   | 27.37±    | 414.83±   | 56.23±    | 70.43±    | 168.67±   | 33.53±    | 188.00±   |
| Standard   | 11.25     | 16.61     | 25.22     | 2.65      | 25.66     | 8.39      | 5.19      | 15.34     | 5.45      | 11.39     |

Levene’s Test • Leveneov test

|            |           |           |           |           |           |           |           |           |           |           |
|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| P-value    | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     |

Welch’s Test • Welchov test

|            |           |           |           |           |           |           |           |           |           |           |
|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| P-value    | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     |

**Table 3.** Means and statistics of number of cycles to fracture (NCF).

|            | F360      | F6        | Hyflex    | iRace     | Neoniti   | O.Shape   | P.Next    | Reciproc  | R-S       | WOG       |
|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Mean       | 762.17±   | 954.16±   | 2758.88±  | 273.67±   | 2765.55±  | 374.88±   | 352.16±   | 843.33±   | 195.61±   | 1096.66±  |
| Standard   | 56.25±    | 83.06±    | 210.14±   | 26.54±    | 171.07±   | 55.90±    | 25.97±    | 76.68±    | 31.77±    | 66.42±    |

Levene’s Test • Leveneov test

|            |           |           |           |           |           |           |           |           |           |           |
|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| P-value    | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.550     | 0.000     | 0.000     | 0.000     | 0.000     |

Welch’s Test • Welchov test

|            |           |           |           |           |           |           |           |           |           |           |
|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| P-value    | 0.000     | 0.000     | 0.550     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     |

**Rezultati**

U svim je usporedbama obavljen Levenov test te, kako nisna su pronađene iste varijance (P < 0,05), proveden je Welchov test (tablice 2, 3 i 4). Srednje vrijednosti cikličkog zamora i statistički podatci nalaze se u tablici 2. Statistički, kad je riječ o otporu, sustavi Neoniti i Hyflex EDM bili su bolji od ostalih (P < 0,05), ali nije bilo statistički značajnih razlika između sustava Wave One Golda i F6 SkyTaper (P = 1,000), sustava One Shape i Protaper Next (P = 0,121), su-

**Table 3.** Srednje vrijednosti i statistički podatci o broju ciklusa do frakture (NCF).

|            | F360      | F6        | Hyflex    | iRace     | Neoniti   | O.Shape   | P.Next    | Reciproc  | R-S       | WOG       |
|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Mean       | 762.17±   | 954.16±   | 2758.88±  | 273.67±   | 2765.55±  | 374.88±   | 352.16±   | 843.33±   | 195.61±   | 1096.66±  |
| Standard   | 56.25±    | 83.06±    | 210.14±   | 26.54±    | 171.07±   | 55.90±    | 25.97±    | 76.68±    | 31.77±    | 66.42±    |

Levene’s Test • Leveneov test

|            |           |           |           |           |           |           |           |           |           |           |
|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| P-value    | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.550     | 0.000     | 0.000     | 0.000     | 0.000     |

Welch’s Test • Welchov test

|            |           |           |           |           |           |           |           |           |           |           |
|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| P-value    | 0.000     | 0.000     | 0.550     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     |
Gold vs F6 SkyTaper (P=1.000), One Shape vs Protaper Next (P=0.121), Reciproc vs F360 (P=0.765), Reciproc vs Wave One Gold (P=0.556) and Revo-S vs iRace (P=0.550).

The NCF were described in Table 3. Neoniti and Hyflex EDM proved to be statistically superior to other systems (P<0.000). However, there were no significant differences between One Shape vs Protaper Next (P=0.999), Wave One Gold vs F6 SkyTaper (P=0.183), Neoniti vs Hyflex EDM (P=1.000), Reciproc vs F360 (P=0.765) and Reciproc vs F6 SkyTaper (P=0.599).

The separated fragment length mean values and statistics are presented in Table 4. The highest values were obtained by F360 and Reciproc. F360 was significantly superior (P=0.000) vs F6 SkyTaper, One Shape and iRace. Reciproc was significantly better to all the other systems (p≤0.001).

### Discussion

In the present study, files with continuous and reciprocating motion and with different alloys, cross-sections, tapers, speeds and torques were studied. The results showed that the systems with CM-Wire and Gold-Wire alloys, reciprocating motion and conventional NiTi instruments with an S cross-section offered better resistance to cyclic fatigue.

A complete bio-mechanical preparation of root canals is an essential factor for endodontic success. Shaping and cleaning of the canal are performed during this phase, and they present great difficulty in curved canals (19-21). Goldberg et al. (22) reported that apical enlargement may produce defects such as apical transportation or zipping, with a risk of endodontic treatment failure.

The cross-section design, the chemical composition of the alloy and the thermo-mechanical process used during the manufacture of the alloy all influence cyclic fatigue (23-25). In the present study, F6 SkyTaper, with a S-shaped cross-section, obtained a higher NCF than other conventional Ni-

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### Table 4. Means and statistics of separated fragments length (mm).

|          | F360 | F6  | Hyflex | iRace | Neoniti | O.Shape | P.Next | Reciproc | R.S | WOG |
|----------|------|-----|--------|-------|---------|---------|--------|----------|-----|-----|
| F360     | 10.48±0.12 | 9.45±0.34 | 9.86±0.42 | 8.06±0.07 | 10.27±0.30 | 9.09±0.12 | 9.90±0.39 | 11.44±0.21 | 10.05±0.55 | 9.85±0.39 |
| Hyflex   |      |     |        |       |         |         |        |          |     |     |
| iRace    |      |     |        |       |         |         |        |          |     |     |
| Neoniti  |      |     |        |       |         |         |        |          |     |     |
| O.Shape  |      |     |        |       |         |         |        |          |     |     |
| P.Next   |      |     |        |       |         |         |        |          |     |     |
| Reciproc |      |     |        |       |         |         |        |          |     |     |
| R.S      |      |     |        |       |         |         |        |          |     |     |
| WOG      |      |     |        |       |         |         |        |          |     |     |

Levene’s Test • Leveneov test
0.000

Welch’s Test • Welchov test
0.000

Games-Howell’s Test • Games-Howellov test
0.000

### Rasprava

U ovom istraživanju ispitivane su iglice s kontinuiranim i reciprocnim kretanjem izrađene od različitih legura, s različitim presjecima, konusima, brzinama i okretnim momentima. Rezultati su pokazali da su sustavi izrađeni od NiTi i Ni-Wire, s reciprocnim kretanjem, te konvencionalni Ni-Ti instrumenti s presjekom u obliku slova S otporniji na ciklički zamor.

Kompletna biomehanička izrađena kanala ključni je čimbenik za uspjeh endodontskog liječenja. Oblikovanje i čišćenje kanala obavljaju se tijekom procesa odlegu CM-wire i Gold-Wire, s reciprocnim kretanjem, te konvencionalni Ni-Ti instrumenti s presjekom u obliku slova S otporniji na ciklički zamor.

Presjek, kemijski sastav legura i termomehanički proces korišten tijekom izrade legure utječe na ciklički zamor (23 – 25). U ovom istraživanju uočeno je da je F6 SkyTaper, koji stava Reciproc i F360 (P = 0,765), susstava Reciproc i Wave One Gold (P = 0,556) te sustava Revo-S i iRace (P = 0,550). Vrijednosti NCF-a prikazane su tablici 3. Neoniti i Hyflex EDM bili su statistički bolji od ostalih sustava (P < 0,000). No, nije bilo statistički značajnih razlika između sustava One Shape i Protaper Next (P = 0,999), sustava Wave One Gold i F6 SkyTaper (P = 0,183), sustava Neoniti i Hyflex EDM (P = 1,000), sustava Reciproc i F360 (P = 0,765) te Reciproc i F6 SkyTapera (P = 0,599).

Srednje vrijednosti duljina separiranih fragmenata i statistički podaci nalaze se u tablici 4. Najveće vrijednosti imali su sustavi F360 i Reciproc. Sustav F360 bio je značajno bolji (P = 0,000) od sustava F6 SkyTaper, One Shape i iRace. Sustav Reciproc bio je značajno bolji od svih drugih (p ≤ 0,001).
Ti systems such as iRace, One Shape and Revo-S, indicating that an S-shaped cross-section offered more flexibility and resistance. On the other hand, CM-Wire alloy (Neoniti and Hyflex EDM) obtained the best results compared to the other systems studied, showing that CM-Wire with memory control is more resistant than the other alloys.

The cyclic fatigue findings of this study (Tables 2 and 3) showed that Group 4 (iRace, 27.37±2.65s, 273.67±26.54 NCF) and Group 9 (Revo-S, 33.53±5.45s, 195.61±31.77 NCF) obtained worse results than the other groups. In contrast, Group 3 (Hyflex EDM, 331.07±25.22s, 2758.88±210.14 NCF) and Group 5 (Neoniti, 414.83±25.66s, 2765.55±171.07 NCF) achieved significantly better results than the other systems. It may also be observed that the S-shaped cross-sectional systems (F360, F6 SkyTaper and Reciproc) obtained better results than the conventional NiTi and M-Wire systems (iRace, Protaper Next, One Shape and Revo-S). Reciprocating motion (Reciproc and Wave One Gold) was found to improve the cyclic fatigue results compared to almost all the continuous motion systems studied (F360, iRace, Protaper Next, One Shape and Revo-S). Regarding separated fragment lengths, F360 (10.48±0.19mm) and Reciproc (11.44±0.21mm) obtained the highest values, while iRace (8.06±0.07mm) and One Shape (9.09±0.12mm) presented the lowest fragments length.

Aminsobhani et al. (26) compared the cyclic fatigue and separated fragment lengths of size 25 Neoniti, Race, Mrwo, TF and Protaper Next files with continuous rotation in 3 simulated canals in a stainless-steel block. In all 3 canals, the Neoniti system obtained better results than other systems: between 400 and 1600 NCF. Statistically, Neoniti was superior to other systems, concluding that CM-Wire (Neoniti) is better than conventional NiTi, R-Phase and M-Wire. For separated fragment lengths, the Race system obtained the lowest mean and TF the highest in group 1. In group 2, Neoniti had the lowest average whereas Race had the highest; and in group 3, Neoniti obtained the lowest mean and TF the highest. In the present study, unlike Aminsobhani et al., Neoniti obtained better fatigue results with continuous rotation also, but both studies agree that Neoniti (CM-Wire) was more resistant than Race with conventional NiTi. As regards separated fragment lengths, the present study is congruent with Aminsobhani et al.’s findings for Group 1, where Race obtained a lower average than Neoniti, unlike in Groups 2 and 3, probably because of the characteristics of each artificial canal in this case.

Kaval et al. (27) investigated the cyclic fatigue of F6 SkyTaper, One Shape, K3XF and TRUShape 3D (Dentsply Tulsa Dental Specialties, Tulsa, USA) files using model with similar characteristics of the block of this study; they observed significant differences between all groups, with F6 SkyTaper obtaining the highest resistance (959±92 NCF). Similar to the findings in the present study, Kaval et al. considered that a double-S cross-section could improve the resistance to cyclic fatigue. Furthermore, F6 SkyTaper was significantly superior to One Shape, as found by Kaval et al.

Pedullà et al. (28) compared size 25 Hyflex EDM, Reciproc and Wave One files in an artificial canal with 60° curvima presjek u obliku slova S, imao viši NCF od drugih konvencionalnih Ni-Ti sustava kao što su iRace, One Shape i Revo-S, što upućuje na to da takav presjek instrumenta omogućuje veću fleksibilnost i bolji otpor. S druge strane, legurom CM-Wire (Neoniti i Hyflex EDM) postignuti su najbolji rezultati u usporedbi s drugim ispitivanim sustavima, što pokazuje da je CM-Wire s membronskom kontrolom otporniji od drugih legura. Nalazi cikličkog zamora u ovom istraživanju (tablice 2. i 3.) pokazali su da su skupina 4 (iRace, NCF vrijednosti 27.37 ± 2.65 s, 273.67 ± 26.54 s) i skupina 9 (Revo-S, NCF vrijednosti 33.53 ± 5.45 s, 195.61 ± 31.77) imale lošije rezultate od drugih ispitivanih sustava. Suprotno tomu, skupina 3 (Hyflex EDM, vrijednosti NCF-a 331.07 ± 25.22 s, 2758.88 ± 210.14) i skupina 5 (Neoniti, vrijednosti NCF-a 414.83 ± 25.66 s, 2765.55 ± 171.07) imale su najveće bolje rezultate od svih preostalih sustava. Moglo se također uočiti da su sustavi koji imaju presjek instrumenta u obliku slova S (F360, F6 SkyTaper i Reciproc) imali bolje rezultate od konvencionalnih sustava Ni-Ti i M-Wire (iRace, Protaper Next, One Shape i Revo-S). Reciprocni pokret (Reciproc i Wave One Gold) pokazao se boljim kad je riječ o cikličkom zamoru u odnosu prema gotovo svim ostalim sustavima s kontinuiranim pokretom (F360, iRace, Protaper Next, One Shape i Revo-S). Kad je riječ o duljini frakturiranih segmenta, sustavi F360 (10.48 ± 0.19mm) i Reciproc (11.44 ± 0.21mm) imali su najveće vrijednosti, a iRace (8.06 ± 0.07mm) i One Shape (9.09 ± 0.12mm) najруako duljine frakturiranih segmenta.

Aminsobhani i suradnici (26) uspoređivali su ciklički zamor i duljine separiranih fragmenta instrumenta veličine 25 sustava Neoniti, Race, Mrwo, TF i Protaper Next s kontinuiranim pokretom okretanja na trima simulacijama kanala u čeličnim blokovima. U svima je Neoniti imao bolje rezultate od ostalih sustava – između 400 i 1600 NCF-a. Statistički je Neoniti imao bolje rezultate od svih ostalih sustava, na temelju čega su zaključili da je CM-Wire bolja legura od konvencionalnih legura Ni-Ti, R-Phase i M-Wire. Kad je riječ o frakturiranim segmentima, sustav Race imao je najmanju srednju vrijednost, a TF najveću u skupini 1. U skupini 2, Neoniti je imao najmanju srednju vrijednost, a Race najveću, a u skupini 3 Neoniti je imao bolje rezultate zamora pri kontinuiranoj rotaciji. Oba istraživanja zaključena su tvrdnjom da je Neoniti (CM-Wire) otporniji od sustava Race izrađenog od konvencionalne nikal-titanijeve legure. Istaknimo da je u vezi s duljinom separiranih fragmenata, naše istraživanje u skladu s istraživanjem Aminsobhanija i suradnika kad je riječ o skupini 1, u kojoj je sustav Race imao nižu srednju vrijednost od sustava Neoniti, za razliku od skupina 2 i 3, što se može pripisati karakteristikama umjetnih kanala na kojima su sustavi ispitivani.

Kaval i suradnici (2) istraživali su ciklički zamor sustava F6 SkyTaper, One Shape, K3XF i TRUShape 3D (Dentsply Tulsa Dental Specialties, Tulsa, SAD) na modelu sličnom našemu. Uočili su snažnije razlike između svih skupina, s tim da je F6 SkyTaper imao najbolje vrijednosti otpornosti (NCF 959 ± 92). Slično našim nalazima, Kaval i suradnici smatraju da presjek u obliku dvoustroga slova S može poboljšati otpor prema cikličkom zamoru. Nadalje, prema tom istraživanju, sustav F6 SkyTaper bio je značajno bolji od One Shapea.
vature with a 3 mm radius. Hyflex EDM gave better results than Reciproc and Wave One, but no significant differences were observed between the latter two. The authors concluded that Hyflex EDM was more resistant than other systems, determining that CM-Wire was more resistant than M-Wire.

In relation to movement, the reciprocating motion did not affect the results. Like Pedullà et al., the Hyflex EDM results were statistically superior to Reciproc in a canal with the same curvature in the present study. Unlike Pedullà et al., in this investigation the reciprocating motion improved the results of other files except in instruments with CM-Wire.

Ersoy et al. (29) studied F360, TF, FlexMaster and Race in a stainless-steel block with an artificial canal measuring 1.5 mm in diameter with a 60° curvature. They observed that F360 was significantly more resistant than the other systems; TF was significantly more resistant than FlexMaster and Race, and there were no significant differences between FlexMaster and Race. They concluded that F360 was the best system, showing that the S-shaped cross-section in systems with continuous rotation improved the cyclic fatigue resistance between systems with shape memory; furthermore, TF was shown to be superior to FlexMaster and Race. The results of the present study, which also compared the files in a 60° canal, are similar to the results obtained by Ersoy et al. in that F360 was significantly better than Race.

Topçuoğlu et al. (30) examined size 25 Wave One Gold, Reciproc and Wave One files in an artificial double S canal, 1.4 mm in diameter and 18 mm in length. The results showed that Wave One Gold obtained the best results in apical and coronal curvature. In the statistical analysis, Wave One Gold was significantly better than Reciproc and Wave One in both curvatures, whereas Reciproc was superior to Wave One in the apical curve; however, there were no significant differences between the latter two systems in the coronal curvature. In conclusion, the authors found that Wave One Gold offered the best resistance in an artificial double S canal. In the present study, Wave One Gold was superior to Reciproc, with similar results to those of Topçuoğlu et al, but there were significant differences in number of cycles to fracture, probably due to the speed and alloy of Wave One Gold.

A study by Keskin et al. (31) compared the resistance to cyclic fatigue and the separated fragments length of size 25 Reciproc Blue, Reciproc and Wave One Gold files at 60° curvature with different radius of curvature. The authors determined that Reciproc Blue obtained the highest significant resistance to cyclic fatigue, and Wave One Gold was significantly better than Reciproc as found by Topçuoğlu et al, confirming that Gold-Wire improved the characteristics of M-Wire. Regarding the length of the separated fragments, they observed no significant differences (P>0.05). In contrast to Keskin et al., the fracture times in the present study were similar for Wave One Gold and Reciproc except in NCF, and significant differences in separated fragment lengths were observed.

Gündogar et al. (32) examined size #25 One Shape, Hyflex EDM, Wave One Gold and Reciproc Blue files at 60° curvature and a 5mm curvature radius. Hyflex EDM obtained significantly better resistance and One Shape was sig-

Pedullà and suradnici (28) usporedivali su instrumente veličine 25 sustava Hyflex EDM, Reciproc i Wave One u umjetno stvorenim kanalima sa zavojem od 60° i radijusom od 3 mm. Hyflex EDM imao je bolje rezultate od sustava Reciproc i Wave One, ali nije bilo značajne razlike između tih dvaju sustava. Autori su zaključili da je Hyflex EDM otporniji od drugih, odnosno da je legura CM-Wire otporna od M-Wire. Kad je riječ o kretanju, recipročno pokretanje nije utjecalo na rezultate. Kao i u tom istraživanju, i u našemu su rezultati sustava Hyflex EDM bili bolji od onih za sustav Reciproc u kanalu s istim zakrivljenjem, no recipročno kretanje u našem je istraživanju poboljšalo rezultate svih drugih instrumenta izrađenih od legure CM-Wire.

Ersoy i suradnici (29) ispitivali su sustave F360, TF, FlexMaster i Race u čeličnim blokovima s umjetnim kanalom promjera 1,5 mm i zakrivljenošću od 60°. Opazili su da je F360 značajno otporniji od ostalih sustava. TF je bio značajno otporniji od sustava FlexMaster i Race, a između njih nije bilo većih razlika. Zaključili su da je F360 najbolji sustav, potvrđujući da presjek u obliku slova S u sustavima s kontinuiranom rotacijom poboljšava otpor prema cikličkom zamenom ako pamte oblik. Nadalje, TF se pokazao boljim od sustava FlexMaster i Race. Rezultati našeg istraživanja, u kojem se također usporedivalo instrumente u kanalu sa zakrivljenošću od 60°, slični su rezultatima Ersoya i suradnika jer je i kod njih F360 imao bolje rezultate od sustava Race.

Topçuoğlu i suradnici (30) ispitivali su instrumente veličine 25 sustava Wave One Gold, Reciproc i Wave One u umjetno napravljenom kanalu oblika dvostrukoga slova S promjera 1,4 mm i duljine 18 mm. Rezultati su pokazali da je sustav Wave One Gold najbolji u apikalnom i koronalnom zavoju. U statističkoj analizi je Wave One Gold bio značajno bolji od sustava Reciproc i Wave One u oba zavojna. Reciproc je bio bolji od Wave One u apikalnom zavojtu, ali nije bilo značajnih razlika u koronalnom zavoju. U zaključcima su autori ustvrdili da Wave One Gold najotporniji u umjetnom kanalu u obliku dvostrukoga slova S, Wave One Gold bio je bolji od sustava Reciproc i u našem istraživanju – rezultati su bili sličnima onima u istraživanju Topçuoğlu i suradnika, ali je razlika bila značajna u broju cikluskih koji su uzrokovali frakturu, vjerojatno zbog brzine i legure sustava Wave One Gold.

Istraživanje Keskin i suradnika (31) uspoređivalo je otpor na ciklički zamor i duljinu frakturiranih segmenta instrumenata veličine 25 sustava Reciproc Blue, Reciproc i Wave One Gold u zavojima od 60° s različitim radijusom zakrivljenosti. Autori su ustvrdili da je sustav Reciproc Blue najotporniji na ciklički zamor, a Wave One Gold bio je značajno bolji od sustava Reciproc, slično kao i u spomenutom istraživanju Topçuoğlu i suradnika, što potvrđuje da legura Gold-Wire ima poboljšane karakteristike legure M-Wire. Kad je riječ o duljinii frakturiranih segmenta, nije bilo statistički značajnih razlika (P > 0,05). Suprotno tom istraživanju, u našem su vremena frakturiranja bila slična za sustave Wave One Gold i Reciproc, osim za NCF, a opažene su i znatne razlike u duljini separiranih fragmenta.

Gündogar i suradnici (32) također su ispitivali instrumente veličine 25 sustava One Shape, Hyflex EDM, Wave One Gold i Reciproc Blue u kanalima sa zavojem od 60° i ra-
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Conclusions

The systems with CM-Wire (Hyflex EDM and Neoniti) were superior to the other systems for cyclic fatigue. For separated fragment lengths, F360 (conventional NiTi) and Reciproc (M-Wire), the lengths were longer.

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Conflict of interests

The authors declare that there is no conflict of interest.

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