

In Vitro comparison of cyclic fatigue resistance of TruNatomy in single and double curvature canals compared with different nickel-titanium rotary instruments

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Abstract

Background The purpose of this study was to compare the cyclic fatigue resistance of newly developed TruNatomy instruments (TRN) in single and double (S-shaped) curvature canals with HyFlex CM (HCM), Vortex Blue (VB) and RaCe (RC) instruments.

Methods Size 20/0.04 taper and size 25/0.04 of HCM, VB and RC were used. For TRN instruments, size 20/0.04 taper (small) and size 26/0.04 taper (prime) were used. The instruments were tested in artificial canals with double curvature (coronal curve; 60° curvature, 5 mm radius and apical curve; 70° curvature and 2 mm radius) and single curvature (60° curvature, 5 mm radius). The number of cycles to failure (NCF) was recorded. Data were statistically analyzed and Weibull analysis was performed on NCF data. Statistical significance was set at $p < 0.05$.

Results TRN and HCM revealed significantly higher NCF compared with the other instruments for both tested sizes in single and double curvature canals ($p < 0.05$). TRN and HCM showed no significant difference in the NCF ($p > 0.05$). The probability of survival was higher for HCM and TRN instruments than VB and RC instruments.

Conclusion HCM and TRN instruments were more resistance to cyclic fatigue than VR and RC instruments in single and double curvature canals. HCM and TRN instruments were anticipated to survive with higher number of cycles than the other tested instruments. RC instrument had the lowest fatigue resistance than the other instruments.

Background

In recent years, various thermomechanical treatments of nickel-titanium (NiTi) alloys have been developed to enhance the mechanical properties and clinical performance of NiTi rotary instruments [1–3]. Thermal processing is considered one of the most effective approaches to modify the transition temperatures of NiTi alloys [1, 4]. It has been reported that alterations in the transformation behavior through heat treatment were effective in enhancing the flexibility and fatigue resistance of NiTi endodontic instruments [2, 5–7].

HyFlex CM instruments (HCM) (Coltene-Whaledent, Altstätten, Switzerland) are manufactured using a distinctive method to control the material memory through a complex heating and cooling treatment [4]. It has been reported that this heat-treated alloy, together with the distinctive design characteristics of the instruments, enhances the flexibility of the instruments but without the shape memory of conventional superelastic forms of NiTi alloy [8–10]. Consequently, the CM NiTi instruments allow better maintenance of the original canal curvature and improved the efficacy of instrument in root canal treatment [9, 11].

Vortex Blue instrument (VB) (Dentsply Sirona, Ballaigues, Switzerland) is another system that control the shape memory of NiTi alloy which improved the fatigue resistance of the instrument [2, 7, 12]. The manufacturing of VB is based on a proprietary Blue technology that forms a blue oxide layer on the surface of the instrument. The blue titanium oxide layer of VB is supposed to enhance the cutting efficiency and wear resistance of the instrument [1, 2, 7, 13].

Fracture of NiTi rotary instruments is occurred by either flexural or torsional fatigue [14, 15]. Most of teeth have curved canals, not only in one but in several orientations and in different planes. Double curvatures (S-shaped) root canals can be troublesome and challenging during root canal instrumentation [3]. It has been reported that the fatigue resistance of NiTi instruments in double curvature canals was lower than in single curvature canals [3, 16]. Decreasing the probability of NiTi rotary instruments fracture has been one of the main aims of manufacturers in order to enhance the safety by using innovative manufacturing processes [17].

Recently, TruNatomy instruments (TRN) (Dentsply Sirona) has been developed as a novel type of heat-treated NiTi instrument with a special design. The TRN shaping instruments are provided in three different sizes which are small (size 20/0.04 taper), prime (size 26/0.04 taper) and medium (size 36/0.03 taper). It has been claimed by the manufacturer that the three shaping instruments of TRN provide a slim shaping which enhances the debridement due to more space is available by this unique design of the instrument. The slim NiTi wire design is 0.8 mm instead of up to 1.2 mm of the most other variable tapered instruments. The TRN instruments are off-centred cross-section design. It was manufactured by using a special NiTi heat-treated wire that supposed to enhance the flexibility of the instrument. According to the manufacture, TRN instruments preserve the structural dentine and tooth integrity due to instrument geometry, regressive tapers and the slim design, along with the heat-treatment of the NiTi alloy [18]. There is no data available on the fatigue resistance of TRN instruments. Consequently, the purpose of the present study was to compare the resistance to cyclic fatigue of newly developed TRN in artificial single and double (S-shaped) curvature canals with other NiTi rotary instruments.

Methods

Cyclic fatigue resistance

Four NiTi rotary instruments with two different sizes were selected for this study. Size 20/0.04 taper and size 25/0.04 of HCM, VB and RaCe (RC; FKG Dentaire, La Chaux-de-Fonds, Switzerland) were used. For TRN instruments, size 20/0.04 taper (small) and size 26/0.04 taper (prime) were used. A total of 120 instruments for each system were divided into two groups ($n = 60/\text{group}$) according to the size of the instrument. Then, each group subdivided into two subgroups ($n = 30/\text{group}$) according to the curvature of the canals (single or double). All instruments were subjected to cyclic fatigue testing using a custom-made stainless steel block containing double curvature canal (60° coronal curvature with a 5 mm radius and an apical 70° curvature with a 2 mm radius) and single curvature canal (60° curvature with a 5 mm radius) which had been used in previous studies [3, 12, 16].

The instruments were operated in the X-Smart motor (Dentsply Sirona, York, PA, USA) with each specified speed and torque according to the manufacturer. The cyclic fatigue test was performed with instruments immersed in saline at 37 ± 1 °C. For each instrument, the number of cycles to fracture (NCF) was

calculated. The fracture length of each instrument fragment was measured. The fractured surface was examined using a scanning electron microscope (SEM) (Stereoscan 260; Cambridge Instruments, Cambridge, UK).

Statistical analysis

The NCF and the fractured fragment length data were statistically analyzed by Kruskal-Wallis and Dunn's multiple comparison tests. The Mann-Whitney test was performed between the data of different sizes of the same instrument. The statistical analysis was performed by using SPSS 20 software (SPSS Inc., Chicago, IL, USA). The level of significance was set at $p < 0.05$. A Weibull analysis was performed on NCF data [19–21].

Results

Table 1 showed the data of NCF and fragment length for TRN, HCM, VB and RC instruments. All the instruments showed significantly higher NCF values for size 20/0.04 than size 25/0.04 in the same curvature ($p < 0.05$). The instruments fractured first in the apical curvature then in the coronal curvature in double curved canal. TRN and HCM revealed significantly higher NCF compared with the other instruments for both tested sizes in single and double curvature canals ($p < 0.05$). VB had significantly higher NCF than RC for both tested sizes ($p < 0.05$). TRN and HCM showed no significant difference in the NCF ($p > 0.05$). The RC instruments had significantly the lowest NCF values compared with other instruments ($p < 0.05$). There was no significant difference in the fragment length value in all groups ($p > 0.05$). The mean length of broken fragments in single and coronal curvature canals was significantly longer than that of fragments in apical double curvature canal ($p < 0.05$).

The SEM images of broken segments in double curvature canal are presented in Figure 1. All the instruments showed the ductile fracture of cyclic fatigue failure. TRN and HCM instruments revealed square cross-section design (Fig. 1A and B; respectively), while VB and RC instruments revealed triangular cross-section design (Fig. 1C and D; respectively).

The data of Weibull modulus (m), correlation coefficient (R^2), characteristic strength (σ_0) and predicted cycles for 99% survival for the NCF data for each group are presented in Table 2. The cumulative probability of survival plots for the NCF data of the tested instruments are presented in Figure 2. The instruments with size 20/0.04 taper (Fig. 2A-C) revealed higher reliability than instruments with size 25/0.04 taper (Fig. 2D-F). HCM and TRN instruments showed higher reliability compared with VB and RC instruments. The predicted cycles for 99% survival of instruments tested in single curvature were higher than the instruments tested in double curvature canal (Table 2).

Discussion

Various factors can affect the fracture resistance of NiTi rotary instruments including alloy composition, manufacturing methods, cross-sectional geometry and flute design [22, 23]. Thermomechanical technology is commonly used for improving the microstructure and transformation behaviors of NiTi instruments in order to enhance the performance of instruments during root canal shaping including the cyclic fatigue resistance [24, 25]. In the present study, HCM and TRN instruments showed greater cyclic fatigue resistance than VB and RC instruments. HCM instruments are manufactured from CM heat-treated alloy that control the instrument memory [4], which allow superior maintenance of the original canal curvature and enhanced the efficiency of instrument in root canal preparation [9, 11]. HCM instruments are characterized by a triangular cross-sectional design displaying three cutting edges except the instruments with size 20/0.04 and 25/0.04 taper, which have a square cross-section design with four blades and four flutes [26] as in the present study (Figure 1B).

The newly developed TRN instruments are manufactured from heat-treated NiTi alloy that supposed to enhance the flexibility and fatigue resistance of the instrument [18]. TRN instruments revealed square cross-section design (Fig. 1A) similar to HCM (Fig. 1B). Both HCM and TRN instruments revealed enhanced fatigue resistance with no significant difference between them. This finding could be attributed to the similarity in the cross-sectional design between HCM and TRN instruments and they are manufactured from heat-treated NiTi alloy. It could be postulated that HCM and TRN instruments might be used more safely in curved canals with double curvature due to their superior fatigue resistance.

TRN instruments revealed higher fatigue resistance than VB and RC instruments. This finding could be attributed to the special heat treatment of the alloy and the design of the instruments that enhanced the fatigue resistance. Heat treatment of the alloy enhances the arrangement of the crystal structure, which might improve the flexibility and strength of the NiTi instruments [10]. In addition, heat treatments of NiTi instruments during or after the manufacturing process reducing the internal stress and surface defects due to the grinding process [10].

VB instruments showed superior fatigue resistance than RC instruments. VB instrument is manufactured from NiTi Blue alloy with a reduced shape memory characteristic which improved the fatigue resistance of the instrument [2, 7, 12]. On the other hand, RC instrument is manufactured from conventional NiTi alloy that influenced the fatigue resistance of the instrument [2, 12]. RC instruments revealed the lowest fatigue resistance among the tested instruments.

The double curvature canals (S-shaped) created more stress on NiTi rotary instruments than in single curvature canals, and consequently the instruments fractured due to cyclic fatigue [12, 16, 25]. The S-shaped canal is one of the most challenging condition in clinical situations during root canal instrumentation with NiTi rotary instruments [16]. In many cases, the double curvatures are not detected in conventional radiographs; consequently, the clinician should be cautious of this probability and continue carefully during root canal instrumentation [3]. In the double curvature canal, the instruments fractured first in the apical curvature followed by the coronal curvature. This finding could be attributed to the abrupt curvature in the apical area with a 2 mm radius compared with the coronal curvature with a 5 mm radius, which is in agreement with the previous studies [3, 16, 27]. There was no significant difference in the mean length of the broken fragments of tested instruments in the same curvature. The instruments fractured at or just below the centre of curvature, which is in agreement with the previous studies [3, 12, 27].

The Weibull analysis revealed that the instruments with size 20/0.04 taper revealed higher reliability than instruments with size 25/0.04 taper. The instruments tested in single curvature canal revealed higher predicted cycles for 99% survival compared with instruments tested in double curvature canal. The probability of survival was higher for HCM and TRN instruments than VB and RC instruments. RC instruments had the lowest predicted number of cycles compared with the other groups. Weibull analysis is an appropriate method to predict the survival probability of NiTi rotary instruments [20, 28].

Conclusion

HCM and TRN had superior fatigue resistance than VR and RC in single and double curvature canals. HCM and TRN instruments were anticipated to survive with higher number of cycles than the other tested instruments. RC had the lowest fatigue resistance than other instruments.

Declaration

Ethics approval and consent to participate

Not Applicable.

Consent for publication

Not Applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

AE, SE, and AM were responsible for the concept, design and implementation of the work, analyzed the participant data and interpretation of data. AE and SE were major contributors in writing the manuscript. All authors read and approved the final manuscript.

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Tables

Table 1 Mean \pm standard deviations, median of number of cycles to failure (NCF), and length (mm) of fractured fragments (FL) of tested instruments

| Groups | Single curvature | | | | Double curvature | | | | | | |
|---------|---------------------------------|--------|-----------------|-------------------------------|------------------|-----------------|-------------------------------|-------------------|-----------------|--------|---------------|
| | | | | | Apical curvature | | | Coronal curvature | | | |
| | NCF | FL | NCF | FL | NCF | FL | NCF | FL | NCF | FL | |
| | Mean \pm SD | Median | Mean \pm SD | Median | Mean \pm SD | Median | Mean \pm SD | Median | Mean \pm SD | Median | Mean \pm SD |
| TRN | | | | | | | | | | | |
| 20/0.04 | 1327.4 \pm 100.7 ^A | 1317 | 5.17 \pm 0.14 | 619.2 \pm 52.3 ^A | 629 | 2.12 \pm 0.07 | 719.6 \pm 79.4 ^A | 716 | 5.07 \pm 0.15 | | |
| 26/0.04 | 1238.8 \pm 106.7 ^a | 1277 | 5.17 \pm 0.13 | 532.8 \pm 51.9 ^a | 523 | 2.12 \pm 0.06 | 609.2 \pm 46.5 ^a | 614 | 5.05 \pm 0.14 | | |
| HCM | | | | | | | | | | | |
| 20/0.04 | 1388.1 \pm 101.9 ^A | 1362 | 5.15 \pm 0.11 | 623.9 \pm 57.4 ^A | 629 | 2.11 \pm 0.09 | 737.8 \pm 73.1 ^A | 715 | 5.08 \pm 0.19 | | |
| 25/0.04 | 1296.3 \pm 80.3 ^a | 1265 | 5.18 \pm 0.18 | 542.6 \pm 52.4 ^a | 544 | 2.13 \pm 0.17 | 618.6 \pm 51.4 ^a | 621 | 5.07 \pm 0.19 | | |
| VB | | | | | | | | | | | |
| 20/0.04 | 704.3 \pm 55.1 ^B | 712 | 5.14 \pm 0.21 | 447.3 \pm 71.7 ^B | 430 | 2.16 \pm 0.11 | 540.4 \pm 55.3 ^B | 549 | 5.04 \pm 0.25 | | |
| 25/0.04 | 529.5 \pm 56.8 ^b | 516 | 5.16 \pm 0.21 | 290.2 \pm 33.5 ^b | 290 | 2.15 \pm 0.17 | 358.4 \pm 44.1 ^b | 351 | 5.08 \pm 0.22 | | |
| RC | | | | | | | | | | | |
| 20/0.04 | 232.3 \pm 29.5 ^C | 230 | 5.13 \pm 0.07 | 122.5 \pm 20.7 ^C | 125 | 2.13 \pm 0.17 | 140.1 \pm 21.1 ^C | 140 | 5.04 \pm 0.15 | | |
| 25/0.04 | 215.9 \pm 22.4 ^c | 215 | 5.14 \pm 0.08 | 93.1 \pm 12.1 ^c | 95 | 2.14 \pm 0.17 | 127.7 \pm 15.1 ^c | 126 | 5.03 \pm 0.18 | | |

Different superscript uppercase letter (column) for instrument size 20/0.04 and lowercase letter (column) for sizes 25/0.04 and 26/0.04 indicate statistically significant difference ($P < 0.05$).

Table 2 Weibull analysis of tested instruments

| Groups | Single curvature | | | | Double curvature | | | | | | | |
|---------|---------------------|---|--|-----------------------------------|---------------------|---|--|-----------------------------------|---------------------|---|--|-----------------------------------|
| | | | | | Apical curvature | | | | Coronal curvature | | | |
| | Weibull modulus (m) | Correlation coefficient (R ²) | Characteristic strength (σ_0) | Predicted cycles for 99% survival | Weibull modulus (m) | Correlation coefficient (R ²) | Characteristic strength (σ_0) | Predicted cycles for 99% survival | Weibull modulus (m) | Correlation coefficient (R ²) | Characteristic strength (σ_0) | Predicted cycles for 99% survival |
| TRN | | | | | | | | | | | | |
| 20/0.04 | 14.7 | 0.92 | 1375 | 1005 | 12.8 | 0.96 | 644 | 449 | 15.2 | 0.97 | 755 | 484 |
| 26/0.04 | 11.7 | 0.84 | 1293 | 874 | 11.8 | 0.94 | 556 | 377 | 10.3 | 0.93 | 630 | 466 |
| HCM | | | | | | | | | | | | |
| 20/0.04 | 16.6 | 0.91 | 1434 | 1069 | 12.6 | 0.98 | 649 | 450 | 13.9 | 0.96 | 771 | 514 |
| 25/0.04 | 15.7 | 0.82 | 1338 | 1014 | 11.9 | 0.97 | 566 | 385 | 11.3 | 0.91 | 642 | 461 |
| VB | | | | | | | | | | | | |
| 20/0.04 | 14.8 | 0.93 | 729 | 535 | 9.9 | 0.94 | 477 | 253 | 10.9 | 0.97 | 565 | 371 |
| 25/0.04 | 10.5 | 0.81 | 555 | 359 | 7.2 | 0.92 | 305 | 192 | 9.5 | 0.91 | 377 | 232 |
| RC | | | | | | | | | | | | |
| 20/0.04 | 11.1 | 0.96 | 245 | 149 | 8.9 | 0.93 | 131 | 66 | 9.9 | 0.93 | 149 | 84 |
| 25/0.04 | 9.1 | 0.93 | 226 | 147 | 6.7 | 0.91 | 98 | 59 | 7.7 | 0.88 | 134 | 82 |

Figures

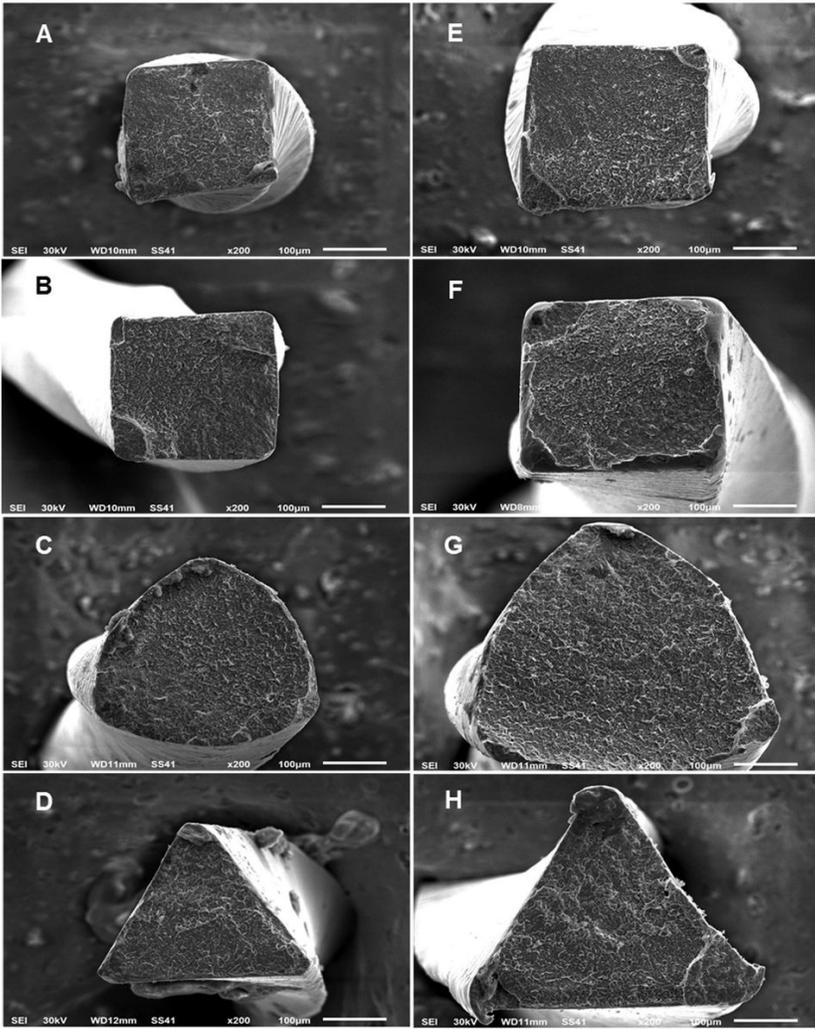


Figure 1
 SEM images ($\times 200$) of fractured fragments in double curvature canals. Fracture of instruments in apical curvature (A-D) and coronal curvature (E-H). (A, E) TRN, (B, F) HCM, (C, G) VB and (D, H) RC; respectively

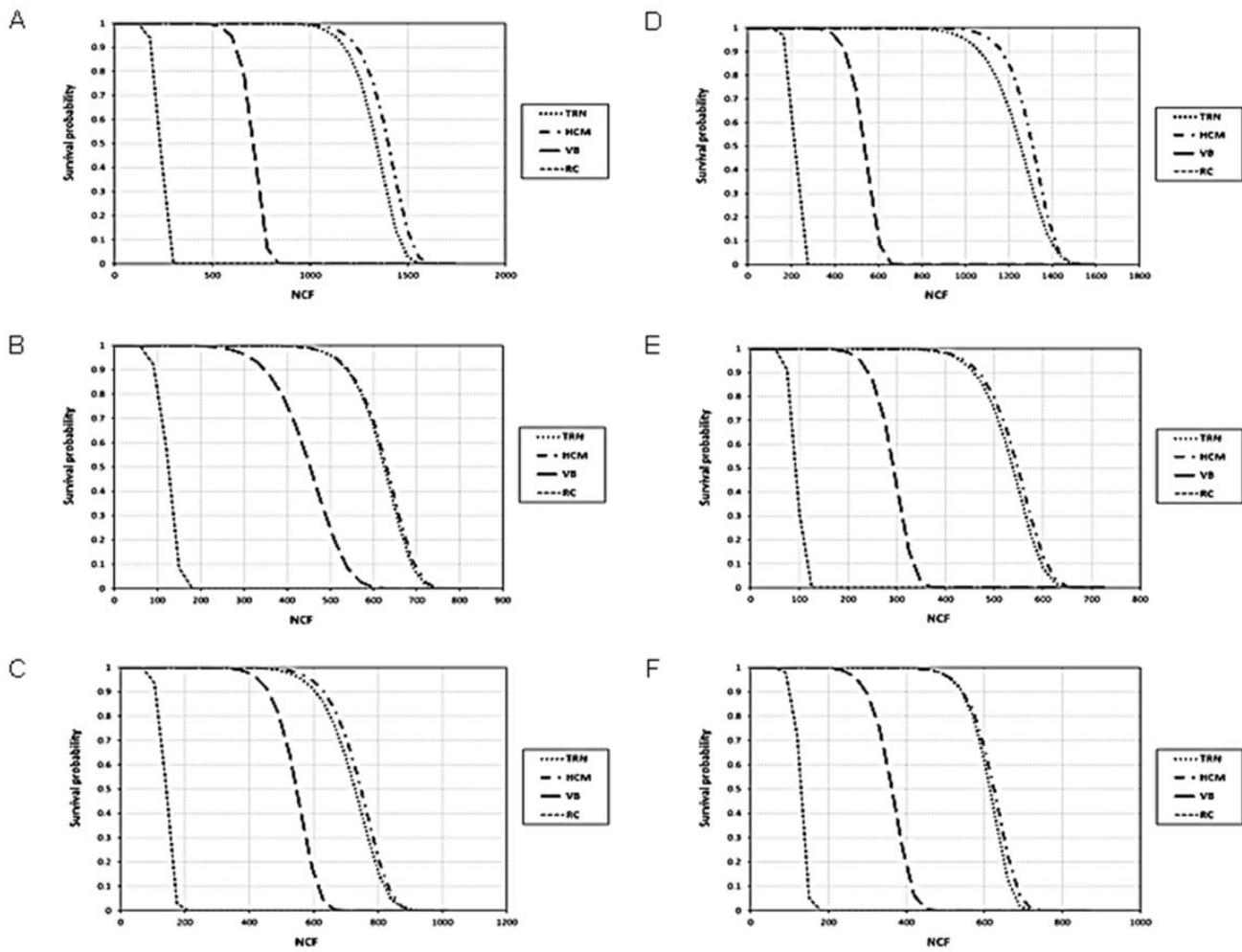


Figure 2
 Survival probability plots for TRM, HCM, VB and RC instruments in single and double curvature canals. (A-C) Instruments with size 20/0.04 taper for single, double apical and double coronal curvatures; respectively. (D-F) Instruments with size 25/0.04 taper for single, double apical and double coronal curvatures; respectively.