

## Original Research Article

# Cyclic fatigue resistance and shaping ability of a new reciprocating instrument

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**Received for publication: December 17, 2024. Accepted for publication: February 20, 2025.**

### Keywords:

endodontics; nickel-titanium; endodontic instruments; mechanical tests.

### Abstract

**Objective:** This study evaluated the cyclic fatigue resistance and the volumetric changes in the root canal after preparation with R-Plus+ and Reciproc Blue instruments. **Material and methods:** A total of 12 instruments (n=6) were used for cyclic fatigue testing: R-Plus+ 25/.08, 40/.05 and Reciproc Blue 25/.08, 40/.05. The instruments were tested in an apparatus simulating a 60° curvature 5 mm of radius, with fracture times measured using a digital stopwatch and video recording. Fractured instruments were analyzed using scanning electron microscopy (SEM). For root canal volumetric change, 18 acrylic blocks with 60° curvature were prepared (n=9). Pre- and post-preparation scans were performed using micro-CT, and canal volume changes were calculated using CTan software. Data were analyzed by unpaired and paired t-tests (P=0.05). **Results:** The R-Plus instruments (sizes 25 and 40) showed significantly longer times to fracture due to cyclic fatigue compared to the Reciproc Blue instruments (P<0.05). No differences in post-preparation root canal volumes were found between the two systems (P>0.05). **Conclusion:** The R-Plus+ instruments demonstrated superior cyclic fatigue resistance compared to Reciproc Blue, with significantly longer times to fracture. However, both systems showed similar root canal volumetric changes after preparation.

## Introduction

The introduction of nickel-titanium revolutionized endodontics, enhancing the safety and effectiveness of the root canal instrumentation phase [14, 30]. Due to their flexibility and cutting efficiency, NiTi instruments offer more safety, reduced instrumentation time, and improved centering ability compared to instruments made of stainless steel [13, 25, 27]. Furthermore, using NiTi instruments is associated with higher healing rates in teeth diagnosed with apical periodontitis than instrumentation with stainless steel instruments [5].

Significant advancements have been made in the NiTi alloy to enhance the safety and efficacy of instruments made from this material. In addition to thermal treatment, variations in kinematics and design features, including the cutting angle of the flutes, cross-section, tip design, and surface treatments, have modified the flexibility, cutting ability, and safety of these instruments [4]. Despite all these advancements, there remains a risk of fracture of NiTi instruments. Fracture or separation of the instruments can occur due to various factors, but it is primarily associated with cyclic and torsional fatigue [2]. Cyclic fatigue occurs when repeated tension and compression stress cycles are generated until the instrument's maximum bending capacity is exceeded. A torsional fracture occurs when the tip or part of the instrument becomes engaged, and the shaft continues to rotate, leading to plastic deformation and eventual fracture [24, 26].

In 2011, instruments with cutting flutes oriented in a counterclockwise direction were developed for reciprocating motion, such as the Reciproc instruments (VDW, Munich, Germany) manufactured using M-Wire thermal treatment [16]. Five years after the launch of the Reciproc files, the Reciproc Blue system was introduced to the market. It maintains the same geometry and kinematics as the conventional Reciproc, but features a different thermal treatment that alters its molecular structure. This modification enhances its cyclic and torsional fatigue resistance and provides greater surface microhardness than its predecessors [10]. These instruments have an "S" cross-section and are available in sizes and tapers: 25.08, 40.06, and 50.05.

The R-Plus+ reciprocating files (Easy Bassi Dental Equipment, Belo Horizonte, Brazil) were recently launched. These instruments are made of NiTi with thermal treatment and have a transformation temperature of around 55°C. They feature an "S" cross-section with constant angles

and are available in lengths of 21, 25, and 31 mm. The files are sold in blister packs containing four different instruments: 15.04, 25.08, 40.05, and 50.05. To date, no studies have evaluated the fracture resistance and preparation characteristics of the R-Plus + instruments.

So, this study aimed to assess the cyclic fatigue resistance and the volumetric change of the root canal after preparation with the R-Plus + and Reciproc Blue reciprocating instruments.

## Material and methods

### Cyclic fatigue

The sample size calculation was conducted using G\*Power v3.1, employing the Wilcoxon-Mann-Whitney test from the t-Test family. The parameters included an alpha error of 0.05, a beta power 0.95, and a ratio of N2/N1 set at 1. This resulted in an ideal sample size of 6 instruments per group. A total of 6 instruments per diameter (n=12) were used: R+ 25/08 and 40/05, and Reciproc Blue 25/08 and 40/05. Before mechanical testing, all instruments were inspected for potential defects or deformities using a stereomicroscope (Stemi 2000C; Carl Zeiss, Jena, Germany) at 16X magnification.

The cyclic fatigue test was conducted using an apparatus designed to simulate the curvature of an artificial stainless-steel canal, as detailed in prior studies [2, 28]. This apparatus featured a 60° curvature and a 5 mm radius. The curvature adjustment was achieved using a guide cylinder (5 mm radius) and an outer arc with a 1 mm deep groove, facilitating the rotation of instruments while maintaining them within the curvature. The cyclic fatigue test was conducted at room temperature (26°C±1°C). An electric motor, VDW Reciproc Silver (VDW, Munich, Germany), was coupled to this apparatus, and instruments were operated with reciprocation motion (Reciproc all function). The time taken for instrument fracture was measured using a digital stopwatch and corroborated by simultaneous filming.

Transverse images of the fractured instruments were obtained using a scanning electron microscope (SEM-JEOL, JSM-TLLOA, Tokyo, Japan) to determine the topographic features of the fractured surface. Before the SEM evaluation, the instruments were ultrasonically cleaned (L100, Schuster, Santa Maria, RS, Brazil) in a saline solution for 3 minutes. The instruments were examined at x100 and x1000 magnification.

### Root canal volumetric change

The volumetric change test used acrylic blocks with root canals having a 60° curvature (IM do Brasil, São Paulo, Brazil). A total of 9 blocks ( $n = 18$ ) were employed. Before preparation with the mechanized instruments, the canals were explored with stainless steel instruments sizes 10 and 15 and then scanned using micro-CT (SkyScan 1174v2, Bruker-microCT, Kontich, Belgium) with the following parameters: a voxel size of 29.7  $\mu\text{m}$ , 50 kV, 800 mA, 180° rotation with a 1.0° step size, and a resolution of 1024 x 1304.

The root canals were prepared using an electric motor, VDW Reciproc Silver, employing the Reciproc All function. The instrumentation followed this sequence for both groups: preparation with a size 25 instrument to two-thirds of the working length, followed by the apical thirds with size 25 and 40 instruments to the entire working length. Files were advanced apically using an in-and-out pecking motion with a 3mm amplitude, applying gentle apical pressure. Each canal received 15 ml of 2.5% sodium hypochlorite solution delivered via a 5 ml disposable syringe (Ultradent, South Jordan, USA) and a 30 Gauge NaviTip needle (Ultradent, South Jordan, USA). After three insertion and removal cycles, the instrument was removed and cleaned with gauze. Each instrument was utilized to prepare three teeth before being discarded. A single, experienced, and trained operator performed instrumentation across all groups. Post-instrumentation, specimens underwent a new micro-CT scan, adhering to the previously mentioned parameters.

The software NRecon v.1.6.3 (Bruker-microCT, Kontich, Belgium) was employed to generate three-dimensional (3D) models, enabling visualization of the internal tooth structure. Subsequently, Data Viewer software (Bruker-microCT, Kontich, Belgium) was utilized to co-register pre-preparation and post-preparation 3D image models. This software employed a customized combination of a registration module based on image intensity similarities, achieving an accuracy greater than one voxel. The canal's volume (in  $\text{mm}^3$ ) was calculated using CTan software (Bruker-microCT, Kontich, Belgium) [8].

### Statistical analysis

The data obtained from all tests were subjected to normality testing. The results revealed an abnormal distribution for the cyclic fatigue data and a normal distribution for the root canal volumetric change data. The unpaired t-test was used to compare the fracture times (cyclic fatigue) and the initial and final volumes between the R-Plus + and Reciproc Blue systems, while the paired t-test was applied to compare the pre-and post-instrumentation canal volumes. A significance level of 5% was adopted. Statistical analyses were performed using GraphPad Prism 9.3 software.

## Results

Table I presents the time (in seconds) until the instruments were fractured due to cyclic fatigue. The R-Plus+ instruments with diameters 25 and 40 showed a longer fracture time than the Reciproc Blue instruments ( $P < 0.05$ ). A statistically significant difference was also identified between the size 25 and 40 instruments of the R-Plus+ system ( $P < 0.05$ ). No differences were observed between the size 25 and 40 instruments of the Reciproc Blue system ( $P > 0.05$ ).

Table II presents the pre- and post-preparation volumes. No differences were observed between R-Plus+ and Reciproc Blue in the initial or root canal volumes after preparation ( $P > 0.05$ ). Statistically significant differences were found between the pre- and post-preparation volumes using the R-Plus+ system ( $P < 0.05$ ) and between the pre- and post-preparation volumes using the Reciproc Blue system ( $P < 0.05$ ).

**Table I** - Mean and standard deviation of time in seconds to fracture of the instruments

	<b>Time (seconds)</b>
<b>R-Plus+</b>	
25/08	745 +/- 159 <sup>a</sup>
40/05	347.2 +/- 77.2 <sup>c</sup>
<b>Reciproc Blue</b>	
25/08	240 +/- 69.8 <sup>b</sup>
40/06	173.8 +/- 48.4 <sup>b</sup>

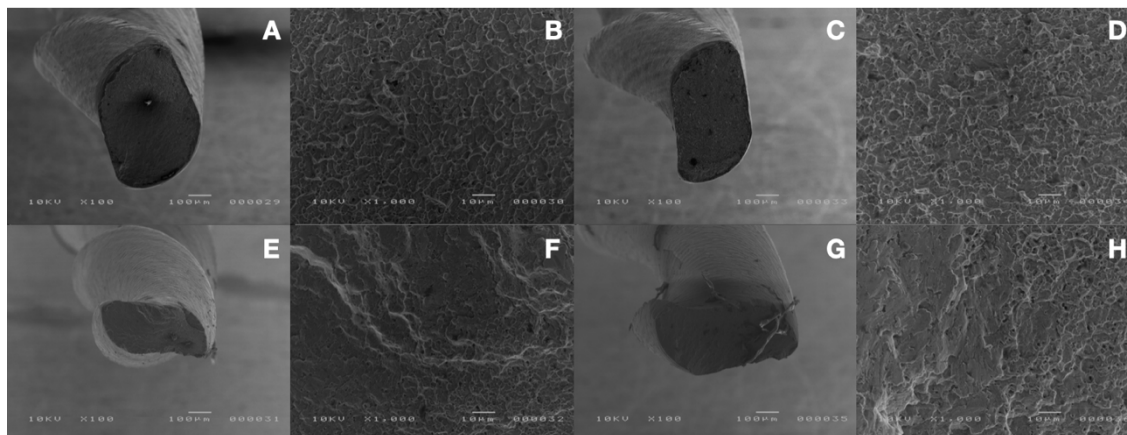
Different lowercase letters indicate statistically significant differences between the instruments analyzed ( $P < 0.05$ )

**Table II** - Mean and standard deviation of volume pre and post preparation

	Volume Pre (mm <sup>3</sup> )	Volume Post (mm <sup>3</sup> )
<b>R-Plus+</b>	1.085 +/- 0.251a	9.426 +/- 0.834b
<b>Reciproc Blue</b>	1.042 +/- 0.390a	8.822 +/- 0.707b

Different lowercase letters indicate statistically significant differences between the volumes ( $P < 0.05$ )

Figure 1 displays SEM images of the fractured 25 and 40 instruments from R-Plus e Reciproc Blue files. These images depict characteristic features indicative of cyclic fatigue behavior observed under SEM.



**Figure 1** - SEM images: A-H) display the fractured surfaces of 25 and 40-diameter instruments after cyclic fatigue test, at 100x and 1000x. A and B) Reciproc Blue 25-diameter; C and D) Reciproc Blue 40-diameter; E and F) R-Plus+ 25-diameter; G and H) R-Plus 40-diameter

## Discussion

The introduction of NiTi instruments in endodontics has significantly improved the efficiency and reliability of root canal preparation. Today, over 200 different NiTi instrument systems are commercially available worldwide, reflecting the widespread adoption of this technology in clinical practice [4]. As a result, it is crucial to conduct studies that evaluate these instruments' mechanical properties and performance to ensure their safety, durability, and effectiveness in root canal treatment. Such research is essential for understanding the nuances of different systems and guiding clinicians in their instrument selection, ultimately enhancing treatment outcomes.

During the preparation of curved root canals, the instrument undergoes repeated cycles of tension and compression, which can lead to the formation of microcracks on its surface. These microcracks can eventually compromise the instrument's integrity, increasing the fracture risk during use [3, 18, 20, 23]. The R-Plus+ and Reciproc Blue reciprocating instrument systems were subjected to cyclic fatigue

testing in our study. The R-Plus+ instruments demonstrated greater resistance to cyclic fatigue than the Reciproc Blue instruments despite sharing similar cross-sectional characteristics. Possible differences in heat treatment and manufacturing processes may have contributed to this outcome. No published studies have specifically been conducted on the R-Plus+ system. However, the Reciproc Blue system has demonstrated greater resistance to cyclic fatigue than other instruments available, such as the WaveOne Gold [6], Rotate, and Mtwo systems [7]. On the other hand, a previous study showed that the 25-diameter instrument exhibited a shorter time to fracture compared to the E-Flex Rec 25.04, Crocodile, and Univy Sense 25.04 and 25.06 instruments. There were also differences in cyclic fatigue resistance between the 25 and 40-diameter instruments of the R-Plus+ system. The 25-diameter instrument exhibited greater cyclic fatigue resistance, which can be attributed to flexibility and fatigue resistance decreasing as instrument size and diameter increase [22]. Although the 25-diameter instrument of the Reciproc Blue

system showed higher cyclic fatigue resistance than the 40-diameter instrument of the same system, no statistically significant difference was observed.

The cyclic fatigue test conducted in our study was performed under static conditions and at room temperature, as widely reported in previous studies [1-3, 10, 23, 28]. Since it is impossible to control all the variables present during the preparation of the root canal system, the test was performed in a controlled laboratory environment to evaluate fracture resistance during the instrumentation of a curved canal. Variables related to laboratory conditions, such as temperature, radius angle of curvature, and handpiece dynamics, may influence the outcome [17, 20]. The method used in our study is widely published and is considered one of the most common methods for assessing cyclic fatigue. Static tests provide crucial insights into how design characteristics and thermal and surface treatments influence cyclic fatigue. In contrast, dynamic tests may complicate the results by introducing torsional stress from the bending tube, making it difficult to distinguish between torsional and cyclic fatigue fractures [15].

The SEM analysis revealed the characteristic patterns of cyclic fatigue in the reciprocating files tested. Following the cyclic fatigue assessment, all evaluated instruments exhibited areas of crack initiation and overload zones, along with numerous dimples across the fractured surfaces [2, 3].

Our study observed no fractures in the endodontic instruments R-Plus+ and Reciproc Blue after repeated use in canals with a 60° curvature. This can be attributed to the operator's experience [19] and the safety of the reciprocating motion [9]. Our findings demonstrate the safety of repeated use – up to three times – of the Reciproc Blue and R-Plus+ instruments in canals with a 60° curvature. However, these results should be interpreted with caution. Further laboratory studies, such as torsional fatigue testing and cutting efficiency evaluations, are necessary for a more comprehensive characterization of the fracture resistance of these instruments. Additionally, clinical studies are also required to assess their clinical safety.

The new R-Plus+ files were recently launched on the market, and according to the manufacturer, their design, specifically the angulation of the helical angle, is intended to enhance the removal of dentinal debris towards the cervical area and facilitate the achievement of working length. To date, no studies have been conducted evaluating these instruments. Regarding shaping ability, these files showed no statistically significant differences in the root canal volume after preparation when compared

to the Reciproc Blue system. This finding is likely due to the similarities between the two systems. Both the R-Plus+ and Reciproc Blue instruments with a 25-diameter have the same taper, and the 40-diameter instruments have similar tapers (0.05 taper for R-Plus+ and 0.06 Reciproc Blue). Furthermore, they share a similar cross-sectional design. These results suggest that both systems produce similar shaping characteristics when used with the same working sequence. However, additional analyses using micro-CT are necessary to assess these instruments' shaping ability more comprehensively. Such analyses would evaluate parameters such as canal centralization, apical transportation, and the thickness of the pericervical dentin. Previous studies have shown that Reciproc Blue instruments with a 25 diameter may lead to canal transportation, and similar concerns may arise with the R-Plus+ system [12, 21].

One of the limitations of the present study is the use of artificial canals in acrylic blocks instead of natural teeth. Although artificial canals do not replicate the natural structural characteristics of dentin, their use allows for the standardization of shape, curvature, volume, cutting resistance, and working length, thereby reducing potential confounding variables in the results. It was also possible to standardize the same curvature angle used in the cyclic fatigue test and the root canal preparation (60°), allowing for a more comprehensive analysis of fracture resistance and performance in cases of canals with a curvature of 60°. The use of resin blocks as a reliable experimental model for studying endodontic preparation and techniques has been established in classical studies by Weine *et al.* [30] and Dummer *et al.* [11]. Further studies evaluating the shaping ability in natural teeth with different anatomies and clinical studies assessing the safety of use are needed for a more comprehensive evaluation.

## Conclusion

The R-Plus+ instruments demonstrated superior cyclic fatigue resistance compared to the Reciproc Blue instruments, with significantly longer times to fracture observed in both the 25 and 40 sizes. However, no significant differences were found in root canal volumetric changes between the two systems after preparation. These findings suggest that while the R-Plus+ instruments offer enhanced fatigue resistance, and both systems perform similarly in terms of canal preparation efficiency.

## Acknowledgments

The authors deny any conflicts of interest related to this study. The authors thank the Fundação de Amparo à Pesquisa do Estado de São Paulo process n. 2024/01063-0 for the financial support.

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