



# Shaping ability of reciprocating single-file systems in severely curved canals: WaveOne and Reciproc versus WaveOne Gold and Reciproc blue

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## Abstract

The aim was to compare the canal straightening of M-wire [Reciproc (VDW, Munich, Germany) and WaveOne (Dentsply Maillefer, Ballaigues, Switzerland)] and gold- and blue-wire heat-treated [Reciproc blue (VDW) and WaveOne Gold (Dentsply Maillefer)] instruments in severely curved root canals. A total of 80 root canals in extracted human teeth with angles of curvatures ranging between 25° and 35° and radii ranging between 3.1 and 8.5 mm were divided into four groups ( $n=20$ ). Based on radiographs taken prior to instrumentation, the groups were balanced with respect to the angle and the radius of canal curvature ( $P=1.0$  and  $P=1.0$ , respectively). All canals were prepared to an apical size 25 according to the manufacturers' instructions. Pre- and post-instrumentation radiographs were superimposed and canal straightening was analysed using a computer imaging programme. Preparation time and instrument failure were also recorded. Data were analysed statistically using ANOVA and Student–Newman–Keuls test. During preparation no instrument fractured. All instruments maintained the original canal curvature well with no significant differences between the instruments ( $P=0.278$ ). Regarding preparation time, no significant differences between the four instruments were obtained ( $P>0.05$ ). Under the conditions of this study, all instruments respected the original canal curvature well. Instruments were safe to use. The use of the gold- and blue-wire heat-treated instruments was not associated with an improved shaping ability.

**Keywords** Blue-wire · Canal straightening · Gold-wire · M-wire · Heat treatment

## Introduction

During the last years, several single-file systems were designed to be used in reciprocating motions [1] to facilitate mechanical root canal preparation. The first systems available on the market were WaveOne (Dentsply Maillefer, Ballaigues, Switzerland) and Reciproc (VDW, Munich, Germany) [2]. Instruments of both systems are manufactured from M-wire nickel–titanium (NiTi) alloy. M-wire consists of 55.8% nickel and 44.2% titanium and of approximately equal proportions of R-phase and austenite at 37 °C [3, 4]. Numerous studies have consistently shown that M-wire has increased flexibility [3, 5, 6] and a significantly increased

cyclic bending fatigue resistance compared to conventional NiTi alloys [6–8].

A peculiarity of the reciprocal mode of operation is the fact that WaveOne and Reciproc actively cut in a counter-clockwise motion, while all other (rotating) root canal instruments actively cut dentine in a clockwise motion. The reciprocal mode of operation is intended to prevent binding of the instrument in the root canal and possible torsional fractures. An increased lifetime of the instruments independent of their cross-sectional design compared to full clockwise rotating instruments has been demonstrated [9, 10]. In agreement, excellent results regarding shaping of severely curved canals [1, 2, 11] and reduction of intracanal microorganisms [12–14] have been reported for these M-wire reciprocating instruments, even when used by novice operators [15].

WaveOne Gold (Dentsply Maillefer) is a reciprocal file that only has the name in common with WaveOne instruments. The movement is identical, but the alloy, cross-section, size and geometry have been changed. The design of these instruments is modified with respect to WaveOne,

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which has in the tip region a cross-section with radial lands and in the middle part of the working length and near the shaft a triangular convex cross-section [2]. The cross-sectional design of the WaveOne Gold instrument is an offset parallelogram (Fig. 1) resulting in only one or two points of contact between the cutting edges and the canal wall. This design results in improved efficiency and an increase in fracture resistance [16]. A wider range of files is available compared to WaveOne (small 20.07; primary 25.07; medium 35.06; large 45.05).

The Reciproc blue instruments (VDW) are identical to the M-wire Reciproc instruments—only the metallurgical properties are changed and improved by the proprietary heat treatment [17]. Furthermore, the files are available in the same sizes as Reciproc, namely R25 (25.08), R40 (40.06) and R50 (50.05).

Gold- and blue-wire heat-treated instruments have a controlled reset effect and are pre-bendable. The main difference to the previous NiTi instruments is that the gold- and blue-wire heat-treated instruments are first ground and then subjected to a special thermomechanical treatment [5]. The typical blue or golden colour is the result of an oxide layer remaining on the instrument surface due to the heat treatment. It has been consistently demonstrated that gold- and blue-wire heat-treated instruments are significantly more flexible than conventional NiTi and M-wire instruments [17–21] and are more resistant to cyclic bending fatigue [21–24].

There are no studies available comparing the shaping ability of M-wire Reciproc and WaveOne with the newer gold- and blue-wire heat-treated Reciproc blue and WaveOne Gold in severely curved canals. The null hypothesis tested was that there is no difference between the M-wire and the heat-treated reciprocating instruments regarding canal straightening in severely curved root canals.

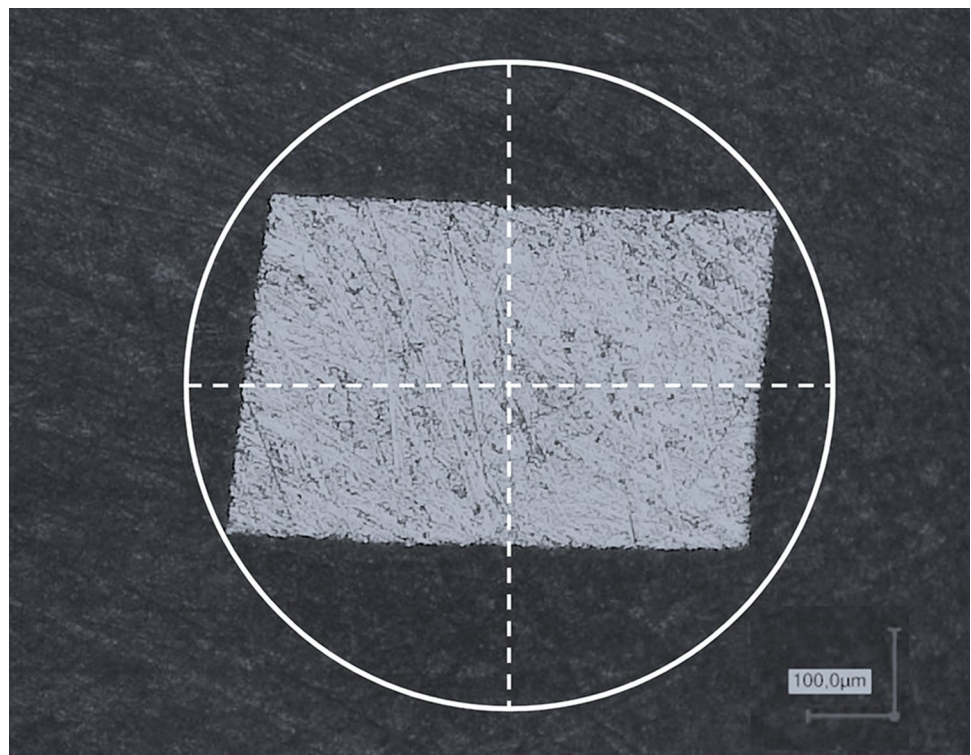
## Materials and methods

### Extracted teeth

A total of 80 extracted human teeth (maxillary and mandibular molars) with at least one curved root and curved root canal were selected. Coronal access was achieved using diamond burs and the canals were controlled for apical patency with a size 10 K-file (VDW). Only teeth with intact root apices, and whose root canal width near the terminus was approximately compatible with size 15 were included. This was checked with silver points sizes 15 and 20 (VDW).

Standardised radiographs were taken prior to instrumentation with the initial root canal instrument of size 15 inserted into the curved canal. The tooth was placed in a radiographic mount made of silicone-based impression material (Silaplast Futur, Detax, Ettlingen, Germany) to maintain a constant position. The radiographic mount comprised of a radiographic paralleling device embedded in

**Fig. 1** Cross-sectional design of the WaveOne Gold instrument



acrylic resin. This device was attached to a Kodak Ultra-speed film (Kodak, Stuttgart, Germany) and was aligned so that the long axis of the root canal was parallel and as near as possible to the surface of the film. The X-ray tube, and thus, the central X-ray beam were aligned perpendicular to the root canal. The exposure time (0.12 s; 70 kV, 7 mA) was the same for all radiographs with a constant source-to-film distance of 50 cm and an object-to-film distance of 5 mm. The films were developed, fixed, and dried in an automatic processor (Dürr-Dental XR 24 Nova, Dürr, Bietigheim-Bissingen, Germany).

The degree and the radius of canal curvature were determined using a computerised digital image processing system [25]. In brief, a point A was determined at the middle of the

file at the level of the canal orifice (Fig. 2). A straight line was drawn aligned parallel to the file image from point A to the point where the instrument deviates from the line (point B). A third point C was made at the apical foramen and the line was drawn from this point to point B. The angle formed by the intersection of the lines determines the canal curvature. Additionally, the radius of the curvature was calculated by measuring length of the chord (BC).

Only teeth whose radii of curvature ranged between 3.1 and 8.5 mm and whose angles of curvature ranged between 25° and 35° were included (Table 1). On the basis of the degree and the radius of curvature, and the distance between the apex and the cemento-enamel junction (CEJ), the teeth were allocated into four similar groups of 20 teeth. The homogeneity of the four groups with respect to the three parameters (canal curvature; canal radius; distance between apex and CEJ) was assessed using analysis of variance (ANOVA) and post hoc Student–Newman–Keuls test (Table 1). At the end of canal preparation, the canal curvatures were redetermined on the basis of a radiograph with the final root canal instrument inserted into the canal using the same technique [25] to compare the initial curvatures with those after instrumentation. Only one canal was instrumented in each tooth.

### Root canal instrumentation

The working length was obtained by measuring the length of the initial instrument [size 10 C-Pilot file (VDW)] at the major apical foramen minus 1 mm. Thereafter, a manual glide path up to ISO-size 15 was prepared using K-files (VDW).

After each instrument, the root canal was flushed with 2 mL of a 2.5% NaOCl solution and at the end of instrumentation with 5 mL of NaOCl using a plastic syringe with 30-g open-ended needle (NaviTip, Ultradent, South Jordan, UT, USA). The needle was inserted as deep as possible into the root canal without binding. All instruments were used in a reciprocating working motion generated by a torque-limited

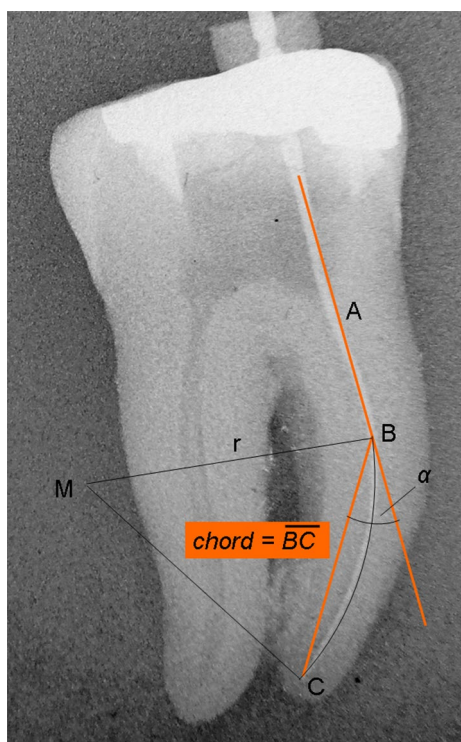


Fig. 2 Determination of root canal curvature and radius of curvature

**Table 1** Characteristics of curved root canals (n = 20 teeth per group)

Instrument	Curvature (°)			Radius (mm)			Distance apex-CEJ (mm)
	Mean ± SD	Min	Max	Mean ± SD	Min	Max	
Reciproc	30.3 ± 3.44	25	35	5.53 ± 1.31	3.1	7.4	11.8 ± 1.43
WaveOne	30.3 ± 3.26	25	35	5.54 ± 1.76	3.1	8.5	12.1 ± 1.71
Reciproc blue	30.2 ± 3.26	25	35	5.54 ± 1.43	3.1	7.9	11.7 ± 1.11
WaveOne Gold	30.3 ± 3.16	25	35	5.53 ± 1.57	3.2	8.1	12.1 ± 1.81
P value (ANOVA)	1.0			1.0			0.767

CEJ cemento-enamel junction

electric motor (VDW.Silver Reciproc motor, VDW) with a 6:1 contra-angle handpiece (Sirona, Bensheim, Germany).

In the Reciproc and Reciproc blue group, a R25 file having a size 25 at the tip and a taper of 0.08 over the first 3 m was used.

In the WaveOne group, a primary reciprocating WaveOne file having a size 25 and a taper of 0.08 was used. In the WaveOne Gold group, a primary file having a size 25 and a taper of 0.07 at the tip was used.

All instruments were used in a reciprocating, slow in-and-out pecking motion with an amplitude of less than 3 mm according to the manufacturers' instructions. The flutes of the instruments were cleaned after three in-and-out-movements (pecks) and the canal was irrigated. Once the instrument had negotiated to the end of the canal and had rotated freely, it was removed. In each of these four test groups, 20 canals were enlarged. Thus, a total of 80 canals were prepared. Instruments were used to prepare four canals only.

## Evaluations

All root canal preparations were completed by one operator whilst the assessments of the canal curvatures prior to and after instrumentation were carried out by a second examiner who was blind in respect of all experimental groups. The operator was equally experienced in the use of the four different systems and underwent a training programme prior to conducting the study. The examiner was the same as in previous studies using the same experimental setup thus he was experienced in assessing the radiographs. Based on the canal curvatures assessed prior to and after instrumentation, canal straightening was determined as the difference between canal curvature prior to and after instrumentation.

The time for canal preparation was recorded and included total active instrumentation, cleaning of the flutes of the instruments, and irrigation. All data regarding preparation time were distributed normally (Kolmogorov–Smirnov test) and were analysed statistically using the analysis of variance (ANOVA) and post hoc Student–Newman–Keuls test. The data regarding canal straightening were analysed using the Kruskal–Wallis test. The level of statistical significance was set at  $P < 0.05$ . The number of fractured and permanently deformed instruments during enlargement was also recorded.

## Results

All canals remained patent following instrumentation, thus, none of the canals were blocked with dentine. With all instruments, no canal had overextension of preparation or loss of working length. The mean straightening of the curved canals is shown in Table 2. Mean canal straightening

**Table 2** Mean degree of straightening of curved canals (°) and SD after canal preparation with the different instruments ( $n=20$  canals in each group)

Instrument	Straightening (°)			
	Mean	SD	Min	Max
Reciproc	1.85	1.10	0	6
WaveOne	1.90	1.02	0	5
Reciproc blue	1.40	0.99	0	6
WaveOne Gold	1.35	0.98	0	4

ANOVA revealed no statistically significant differences between the instruments ( $P=0.278$ )

ranged between 1.35° (WaveOne Gold) and 1.90° (WaveOne Gold) (Fig. 3) with no significant differences between the four instruments ( $P=0.278$ ).

During the preparation of the curved canals, no deformation or fracture of an instrument was noted.

The mean time taken to prepare the canals with the different instruments is shown in Table 3. No significant differences were found between the four different instruments ( $P > 0.05$ ).

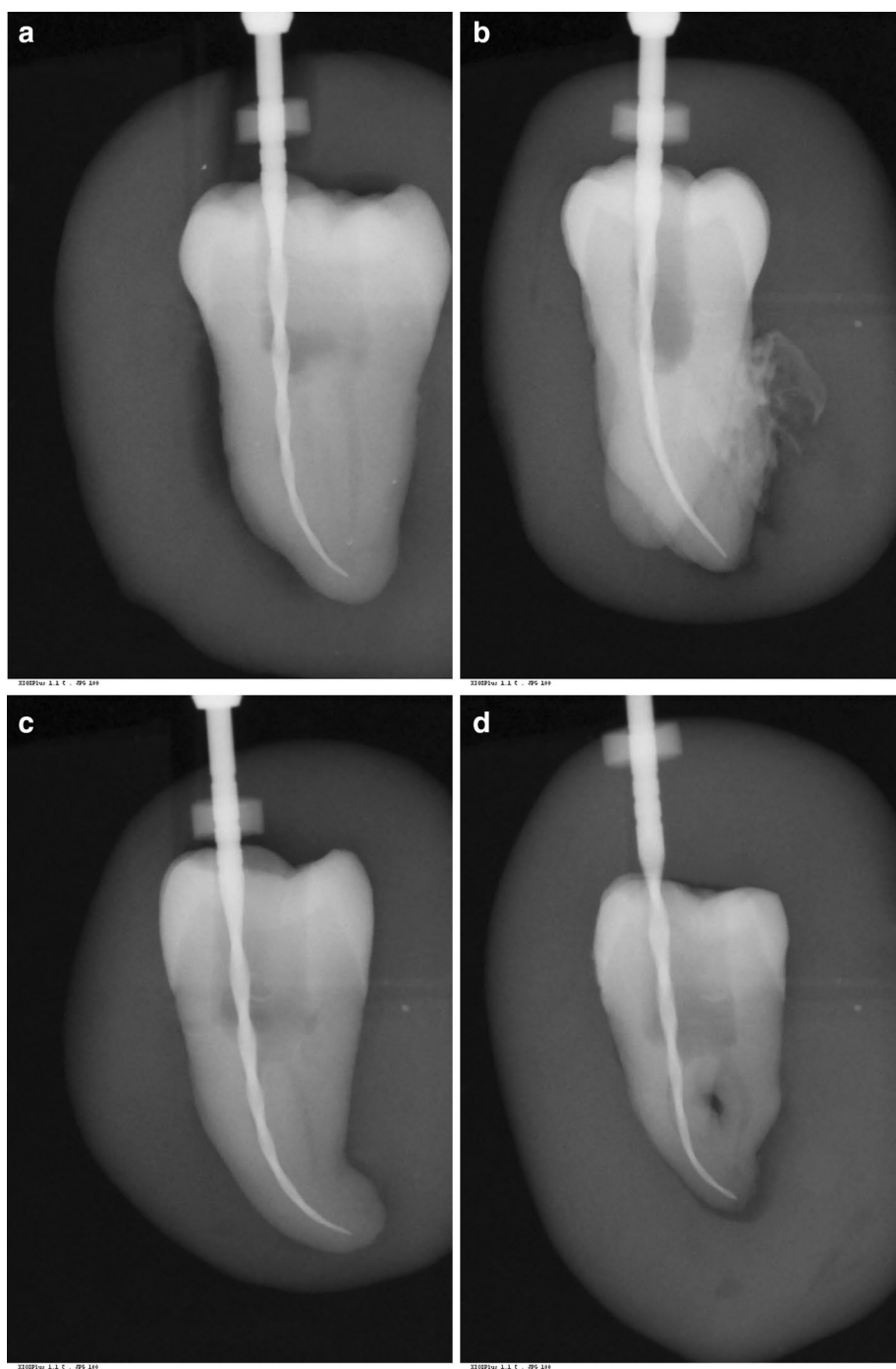
## Discussion

The aim of this study was to assess and compare the shaping ability of two M-wire and two gold- or blue-wire heat-treated reciprocating single-file systems. The results of the present investigation failed to reject the null hypothesis as no differences between the four reciprocating single-file systems regarding canal straightening were found.

Attempts were made in the present study to ensure comparability of the experimental groups. Therefore, the teeth in all groups were balanced with respect to the length (distance between apex and CEJ) and the apical diameter of the root canal. Moreover, based on the initial radiograph the teeth were also balanced with respect to the angle and the radius of canal curvature. To achieve this, a computerised digital image processing system was used to determine both the angle and the radius of curvature [25]. The homogeneity of the four groups with respect to the defined constraints was examined using analysis of variance (ANOVA) and post hoc Student–Newman–Keuls test. According to the  $P$  values obtained (Table 1), the groups were well balanced.

Regarding the assessment of canal straightening used in the present study, it can be argued that three-dimensional analysis, e.g. using micro-CT, might provide more detailed results. However, it was decided to use a two-dimensional evaluation using standardised radiographs as done in previous studies for several reasons: (1) to ensure that well-defined evaluation parameter was obtained that allows

**Fig. 3** Representative postoperative radiographs of curved canals prepared with **a** Reciproc, **b** WaveOne, **c** Reciproc blue and **d** WaveOne Gold



**Table 3** Mean preparation time (sec) and SD with the different instruments

Instrument	Mean	SD
Reciproc	37.4	8.1
WaveOne	31.6	13.8
Reciproc blue	30.8	15.8
WaveOne Gold	31.7	9.7

direct comparison between studies [25]. Moreover, Hülsmann stated in his editorial: “The micro-CT technique can deliver three-dimensional images with valuable information on shaping outcomes ..., but studies using conventional radiographs remain relevant.” [26]. (2) The teeth used in the present study were thoroughly selected and the groups

were well balanced with regard to several anatomical parameters with *P* values ranging between 0.767 and 1.0 (Table 1). Thus, the chance of bias due to unequal distribution of canals with a second buccal–oral curvature was considerably low. (3) In a recent review on methods and models to study root canal instruments, the authors argued that at least about 20 µm and in worse cases even about 40 µm of dentine removal is required to detect changes in surface area when using micro-CT [27]. Based on previous studies conducted under identical experimental conditions mean canal straightening for the instruments used was expected to be in the range of 0.04 mm [28], hence, in the range of the resolution of micro-CTs. Thus, based on the results of the previous study it was questionable if micro-CT evaluation will provide any benefits.

In the present study, all canals were prepared to an apical size of 25. Prior to the use of the tested instruments, a glide path equivalent to ISO size 15 was created. According to recently published results, it can be ruled out that this glide path preparation had an adverse impact on the final results regarding canal straightening. Glide path preparation in canals with curvature angles between 25° and 35° (the same range of curvature as in the present study) even to ISO size 20 using manual stainless steel K-files had no effect on canal straightening or apical transportation [29] and did not produce any canal aberrations [30].

Regarding canal straightening, the results for all four instruments were comparable to those of recent investigations under similar experimental conditions [2, 31, 32]. Saber et al. reported canal straightening of 1.8° for WaveOne and 1.6° for Reciproc [31] and these values are nearly identical with those obtained in the present study (Table 2). Both heat-treated reciprocating instruments (Reciproc blue and WaveOne Gold) performed equally well compared to their M-wire counterparts as no significant differences regarding canal straightening were obtained. Reciproc and Reciproc blue have identical design features and dimensions (diameter and taper) with the only difference of the proprietary blue-wire heat treatment. Thus, when comparing the results of these two instruments the conclusion that the heat treatment had no impact on the shaping ability in severely curved canals is justified. With regard to the comparison between WaveOne and WaveOne Gold no significant differences between these two instruments were obtained. This is in agreement with the results regarding canal transportation and centring ability of a previously published study [33]. However, as WaveOne Gold differs from WaveOne not only in terms of metallurgical aspects but also with regard to the cross-sectional design and taper a direct inference on the impact of the gold-wire heat treatment on the shaping ability cannot be drawn.

Although no significant difference concerning canal straightening was observed between the M-wire and the

heat-treated instruments (Table 2), a more detailed look at the results reveals a trend that the use of the gold- and blue-wire heat-treated instruments was associated with less canal straightening. Obviously, despite the fact that severely curved canals were used in this study the anatomy of the selected root canals was not complex enough to reveal a distinct correlation between gold- and blue-wire heat treatment and improved shaping abilities. It seems reasonable to assume that in more complex canal anatomies this correlation would become clear. Thus, further studies using s-shaped canals or canals with abrupt curvatures with small radii are warranted to gain further information with regard to the clinical relevance of using gold- or blue-wire heat-treated instruments.

During the present study no instrument fractured. All instruments were used to enlarge four curved canals and based on the results of this laboratory study, it can be recommended that the reciprocating single-file systems tested can be used to enlarge at least four canals without an increased risk of fracture.

In the present study, the preparation time included active instrumentation, cleaning the flutes of the instruments and irrigation (Table 3). The time required to create the glide path up to size 15 was not included. No significant differences between the four instruments tested were obtained ( $P > 0.05$ ). However, in previous studies Reciproc was significantly faster compared to WaveOne [2, 31]. This marginal discrepancy might be due to differences in operator experiences. Though, from a clinical point of view the differences between the four instruments assessed in this study were negligible.

## Conclusions

Within the parameters of this study, gold- or blue-wire heat-treated instruments were not associated with improved shaping abilities as all single-file systems maintained root canal curvature equally well and were safe.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

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