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Original paper

Title: The Shaping Advantage of M-wire Compared with Conventional Nickel-titanium Rotary Instruments in Heavy Curvature Canals

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Abstract

Background : The purpose of this study was to evaluate the shaping advantage of M-wire NiTi ProTaper NEXT (PTN) compared with a conventional NiTi ProTaper Universal (PTU) file in heavy curvature canal. The shaping ability was measured by the amount of canal cutting and transportation between the PTN and conventional PTU.

Methods: Root canal shaping by the PTN and conventional PTU was classified into two experimental groups according to the final tip size, ISO #25 or ISO #40. Eighty-four J-shaped root canals (10°, 20°, 30° apical curvature) in resin block were used.

Results: After adjusting for the level and canal wall side, the mean transportation did not significantly decrease between the PTN and PTU with ISO #25. Significantly less deviation occurred with the PTN and PTU between 10° and 30° using ISO #40.

Conclusions: The M-Wire NiTi PTN improves file flexibility and enables accurate canal shaping for heavy curvature canals.

Key words: M-wire, ProTaper NEXT, ProTaper Universal, shaping ability,
apical curvature

Introduction

Rotary dental files with a NiTi alloy containing 56% (wt) Ni and 44% (wt) Ti have significantly changed root canal preparation. The NiTi alloy has a cubic crystal structure with an austenite phase above the shape recovery temperature (1). The austenite phase changes to martensite under force and temperature, but when the stress is released, the phase returns to austenite (2, 3). Consequently, the NiTi alloy has a shape memory effect and superelasticity without plastic deformation, which is advantageous for instruments used for root canal preparations.

Given the development of NiTi endodontic instruments targeted at root canals with complex anatomical configurations, the shape memory and superelastic properties of such NiTi instruments has helped prevent endodontic accidents (such as ledges, root canal perforations, apical transportation, and file fractures) (4,5). Currently, unique heat and mechanical treatments can be used to complement the mechanical properties of NiTi alloys to improve flexibility and fatigue resistance.

In 2007, Sportwire LLC (Langley, OK, USA) developed a unique heat treatment process with the aim of producing a more flexible NiTi alloy with better fatigue resistance than conventional NiTi alloys (6). Additionally, Berendt developed a NiTi composition in which trace elements of less than 1% were added to produce a NiTi alloy (7). Under a heat treatment process, the M-Wire alloy converts to a rhombohedral (R) phase (intermediate temperature phase between austenite and martensite) and the elasticity changes with the change from austenite to martensite. Therefore, the flexibility of a NiTi endodontic file can be enhanced by modification (8,9). Additionally, NiTi alloy converted to the R phase is conventionally produced by cutting; however, NiTi files are produced by a non-cutting rolling step, thereby increasing the file fatigue resistance and fracture resistance.

The ProTaper NEXT (PTN) file used in this study is a next generation model of ProTaper Universal (PTU), which is a modification of the conventional NiTi alloy PTU and uses M-Wire. PTN was developed as a file suitable for severely curved root canals given its increased flexibility and fracture resistance. Compared with conventional NiTi PTU, the M-Wire NiTi PTN suppresses the occurrence of micro-cracks during root canal formation (10,11). Root canal wall displacement after cutting (12-15), fatigue resistance (16-18), and file breakage resistance (19) of M-Wire PTN have been previously studied to determine the shaping ability. However, no report has objectively compared the different curvature canal range and shaping ability of M-Wire PTN with a conventional NiTi PTU in the same shaping system. The purpose of this study was to analyze the advantages of the M-Wire NiTi PTN and the relationship between the

amount of the canal wall removed and canal center transportation compared with a conventional NiTi PTU.

Materials and Methods

Simulated root canal block and experimental design

Eighty-four simulated J-shaped canal blocks with a curvature of 10°, 20° and 30° (root apex size #15, root canal length 19 mm (working length), Nissin Plastic training Block S4-U1, Nissin, Kyoto) were used. Three different angle J-shaped canal blocks (S4-U1-10°,20°,30°) were cut 19.0mm(S4-U1-10°), 18.5mm(S4-U1-20°), and 18.0mm (S4-U1-30°) from the root canal orifice at the top of the model by IsoMet (BUELER, Tokyo, Japan) and adjusted to allow apical foramen penetration (Fig. 1).

We use a NiTi PTN file (Dentsply Sirona, Ballaigues, Switzerland) made by M-Wire and a conventional NiTi PTU file (Dentsply Sirona) as a control.

For root canal preparation, there were two final apical sizes for four groups, ISO #25 (1 PTN, 2 PTU) and ISO #40 (3 PTN, 4 PTU). Using a J-shaped canal block, measurements were made by classifying the blocks into 2 groups. The apical size and file taper (diameter increase amount / mm) of each NiTi file were PTN X1 (17/04 (tip diameter/taper), X2 (25/06), X3 (30/07), X4 (40/06), and PTU F1 (20/04), F2 (25/06), F3 (30/06), and F4 (40/06), which were used to set the final apical size to ISO #25 and #40.

Three curvature blocks (10°, 20°, 30°; each n = 7) were used, giving 21 total canal blocks for each of the ISO #25 (1:PTN, 2:PTU) and ISO #40 (3:PTN, 4:PTU) groups. Therefore, 84 canal blocks were tested. All root canal models were attached to the *Endo Training Model Castillo* (VDW, Frankfurt, Germany), and root canal formation was performed in a situation where the root canal morphology could not be confirmed.

Root canal preparation

Before starting root canal preparation with the M-wire PTN and conventional PTU files, flare formation (straight line) in the upper third of all root canal orifice openings and smooth file guide path creation (glide path) up to the root apex were performed. Flare formation was performed using PTN SX and PT SX files (Dentsply Sirona, Ballaigues, Switzerland), which are used for straight line formation only. Furthermore, the glide path was confirmed up to #15 using a ISO#15 stainless-steel K file (Dentsply Sirona). All NiTi files were washed with purified water using a dedicated engine (X Smart plus, Dentsply Sirona), and 1 mL of EDTA-gel Glide (Dentsply Sirona) was applied to the NiTi files.

Root canal preparation using PTN and PTU files was performed by a single dentist with more than 7 years of experience using NiTi rotary files. The following procedure was performed and files were exchanged after every five root canal formations.

1. ISO #25 PTN: Using two X1 and X2 files sequentially, select the X Smart plus PTN mode (300 rpm, 2.0 Ncm), perform root canal cleaning with distilled water by plastic syringe when exchanging files, and reach the working length (19 mm) of the X2 file to complete the root canal formation.

2. ISO #25 PTU: Using S1(17/02), S2(20/04), F1 and F2 files in sequence, select the PT mode (250 rpm, 3.0–1.0 Ncm), perform root canal cleaning with 2 ml distilled water when exchanging files, and let the F2 file reach its working length.

3. ISO #40 PTN: Using X1, X2, X3, and X4 files in sequence, select the PTN mode (300 rpm, 2.0 Ncm), perform root canal cleaning when exchanging files, and let the X4 file reach its working length.

4. ISO #40 PTU : Using S1, S2, F1, F2, F3, and F4 files in sequence, select the PT mode (250 rpm, 3.0–1.0 Ncm), perform root canal cleaning when exchanging files, and save the F4 file after reaching its working length.

Evaluation of the canal shaping

The amount of resin removed in the outer and inner side of the curved root canal was compared. A stereoscopic microscope Olympus SZX16 and a digital camera DP71 (Olympus, Tokyo) were used for the measurement. The transparent root canal models before and after root canal preparation was superimposed with digital images, and the resulting image was transferred to a PC and measured. The measurement points were 1, 2, 3, 4, and 5 mm from the apex, and the increase in the root canal width on the outer and inner side was measured and statistical processing was performed (Fig. 2).

Root canal center transportation was measured as the amount of root canal wall cutting in the outer and inner sides of the curved root canal, and the median displacement of the root canal before and after preparation was measured. We measured ①the distance between shaping and original inner canal wall, ②the distance between shaping and original outer canal wall, and ③the canal width of the shaped canal. The canal center transportation was calculated as centering ratio. Centering ratio was calculated as equation $(\text{①} - \text{②} / \text{③})$ (16). The shaping becomes more centered as the centering ratio approaches zero.

Statistical analysis

The amount of root canal wall cutting and root canal transportation was measured using statistical analysis using one-way analysis of variance and a multiple comparison test using *Bonferroni–Dunn* test. The level of significance was test at $p < 0.05$.

Results

The root canal shaping ability was evaluated according to the amount of resin removed and the root canal transportation. In experimental groups 1 to 4, the amount of resin removed was shown by comparing M-wire PTN and conventional PTU for each curvature (10°, 20°, 30°; Figs. 3, 4, 5). The root canal transportation was classified by PTN and PTU file (Tables 1 and 2).

Shaping ability of the final apical size ISO #25

The removal of resin by PTN decreased in both the inner and outer side in the ISO #25 curvatures of 10° to 30° compared with the PTU (Fig. 3a,4a,5a) . Alternatively, the amount of resin removed by PTU on the inner and outer sides was small at 10° to 20° curvatures. The amount of resin removed by PTU a little increased at the 30° curvature: the apex side was 1 mm on the outer side, and the apical side is 4 mm and 5 mm on the inner side, although there is no significant difference (Fig.5a).

The change in the root canal transportation for both PTN and PTU was within 0.02 mm for all root canals with a curvature of 10° to 30° (Table 1).

Shaping ability of the final apical size ISO #40

Even with ISO #40 and PTN, the amount of resin removed from the inner and outer sides was less than those in the PTU group for all root canals with a curvature of 10° to 30° (Fig. 3b, 4b, 5b) . For ISO #40 and PTN, the amount of resin removed was significantly less than the PTU group at 1 - 5 mm on the inner side with a curvature of 10° (Fig.3b) and 1 mm on the outer side at 30° (Fig.5b). The amount of resin removed by PTN only increased from 4 to 5 mm on the inner side compare with outer side at 20°(Fig.4b), 30° (Fig.5b). This tendency was similar to that of the group. The amount of resin removed by PTU with ISO #40 significantly increased by 1 mm on the apex side for all a curvatures, and the cutting amount on the inner side increased from 4 to 5 mm on the apex side ($p<0.05$) (Fig.5b).

The change in the root canal transportation was less than 0.05 mm in the 10° to 20° curvatures using PTN, but 0.06 mm at the apex 4 to 5 mm into the root with a 30° curvature. The transportation further significantly increased to 0.08 mm ($p<0.05$) (Table2).

Alternatively, the root canal transportation of PTU showed a displacement of 0.1 mm or more on the outer side of the apex side at 1 mm in all the root canals with a curvature of 10° to 30°. In the PTU, the canal transportation on the inner side increased to 0.07 mm and 0.08 mm at 3 and 4 mm, respectively, even with a curvature of 10°, and the inner side displacement of the root canal of 30° also increased to 0.07 mm and 0.08 mm at 4 and 5 mm, respectively (Table 2).

Discussion

The mechanical properties of the NiTi file depends on the processing method of the file and the surface finishing method, but it has been reported that the change in crystal structure by the heat treatment process affects the flexibility of NiTi alloys (20-23). The PTU used in this study has super-elasticity by the stress-induced transformation of the martensitic phase with a monoclinic crystal structure to the austenite phase, which is the cubic crystal structure of a conventional NiTi alloy (24). Alternatively, PTN, which is a NiTi alloy processed into M-wire by heating and cooling, coexists with austenite, martensite, and R phases, and has a monoclinic martensite phase and R phase (16-18). Because the elastic modulus is less than that of the austenite phase, the initial flexibility is improved. Additionally, the M-wire NiTi alloy is more flexible than the conventional NiTi alloy because the austenite phase undergoes a martensitic transformation due to the stress on the file when forming a curved root canal. The stress load on the file is reduced, which reduces file corruption (19).

In this study, the usefulness of the M-wire NiTi alloy was analyzed by comparing the cutting characteristics of PTN and PTU under a stress load (formation of a curved root canal). The root canal formation using root canal models with different apex curvatures of 10° to 30° were analyzed with final apical sizes of ISO #25 and ISO #40. There was a large difference in the displacement of the root canal wall between the groups. In the ISO #25 group, there was no significant difference in the amount of resin removed or canal transportation associated with the change in the bending angle in PTN and PTU.

In the ISO #25 group, the amount of resin removed by PTN and PTU was 1 to 5 mm from the apex of the inner and outer bays for curved root canal angles of 10°, 20°, and 30°. The measured value was less than 0.05 mm. Furthermore, the root canal transportation was less than 0.05 mm and both files could form the root canal and maintain the original anatomical root canal morphology. The NiTi file with a ISO #25 tip showed that the shaping ability of the conventional and M-wire type NiTi alloy files were similar and useful for root canal preparation of curved root canals between 10° to 30°.

Alternatively, in the ISO #40 group, the amount of resin removed significantly changed depending on the root canal curvature in the PTN and PTU file. The PTU increased the lateral displacement by 1 mm from the apex, and 4 mm and 5 mm from the apex in the inside of the root canal between 10° to 30°. The risk of transportation and canal perforation in the curved root canal was observed. However, the PTN maintains the original root canal morphology when the amount of resin removed in the inner and outer sides was 1 to 3 mm and from the apex is 0.1 mm or less between 10° to

30° canals. Alternatively, for the 30° curvature canal, the inner side cutting of 4 mm and 5 mm from the apex tended to be as high as that of the PTU. The PTN obtained by converting the NiTi alloy into the R phase by heat processing improved the root canal followability and suppressed the transport on the outer bay side of the apex. It is necessary to be careful of accidents, such as strip perforation during root canal formation on the inner side, when using the 30° curvature.

Because the PTN and PTU used in this study are similar file systems for complete root canal formation with multiple lines, the flexibility of the M-Wire NiTi alloy is useful for proper root canal formation. Additionally, the M-wire type NiTi alloy single file preparation system (Reciproc, WaveOne file) completes root canal formation with only one file, the root canal wall displacement is less than the conventional NiTi PTU, and the root canal transportation is reduced. Additionally, the M-wire PTN is reported to retain anatomical morphology (23, 24). Finally, the M-wire PTN has excellent fatigue resistance and torsion resistance regardless of the difference in file systems used for root canal preparation.

Conclusion

The amount of canal wall removed and transported by M-wire ISO #40 PTN was less than that of conventional ISO #40 PTU in 10° to 30° curvature canals and the original root canal form was maintained, although no significant difference in the shaping ability for curvature canals by both PTN and PTU of ISO #25. The M-Wire PTN improves file flexibility and enables accurate canal shaping for wide and heavy curved canals

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Figure legends

Figure 1. J-shaped simulated root canals made of clear resin with apical size of 0.15 mm (ISO #15) and (a) 10°, (b) 20°, and (c) 30° apical curvatures.

Figure 2. Pre- and post-instrumentation images were superimposed and the difference between the canal configuration before and after instrumentation were measured in each of the five traced levels.

Figure 3. Total amount of removed resin (mm) at the different levels after root canal preparation for 10° apical curvature canals by (a) ISO #25 PTN, ISO #25 PTU, and (b) ISO #40 PTN, ISO #40 PTU.

Figure 4. Total amount of removed resin (mm) at the different levels after root canal preparation for 20° apical curvature canals by (a) ISO #25 PTN, ISO #25 PTU, and (b) ISO #40 PTN, ISO #40 PTU.

Figure 5. Total amount of removed resin (mm) at the different levels after root canal preparation for 30° apical curvature canals by (a) ISO #25 PTN, ISO #25 PTU, and (b) ISO #40 PTN, ISO #40 PTU.

Table 1. Statistical analysis of canal transportation at different levels after root canal preparation using a final apical size of ISO #25 in 10°, 20°, and 30° apical curvature models by PTN and PTU.

apical curvature level (mm)	PTN			PTU		
	10°	20°	30°	10°	20°	30°
1	0.00±0.00	0.00±0.01	0.00±0.01	0.00±0.00	-0.01±0.01	-0.02±0.01
2	0.00±0.00	-0.01±0.00	0.00±0.01	-0.01±0.01	0.00±0.00	-0.01±0.01
3	-0.02±0.00	0.00±0.01	0.00±0.00	-0.01±0.01	0.00±0.00	0.00±0.01
4	-0.02±0.00	-0.01±0.01	0.02±0.01	-0.01±0.00	0.01±0.00	0.02±0.01
5	0.00±0.00	0.00±0.00	0.00±0.01	0.01±0.01	0.01±0.01	0.03±0.02

Mean±SD (mm)

Table 2. Statistical analysis of canal transportation at different levels after root canal preparation using a final apical size of ISO #40 in 10°, 20°, and 30° apical curvature models by PTN and PTU.

apical curvature level (mm)	PTN			PTU		
	10°	20°	30°	10°	20°	30°
1	-0.03±0.02 *	-0.05±0.01 *	-0.05±0.03 *	-0.10±0.02 *	-0.10±0.03 *	-0.13±0.03 *
2	0.00±0.01	-0.02±0.01	-0.02±0.02	0.01±0.02	-0.04±0.01	-0.05±0.02
3	0.00±0.01 *	-0.01±0.01	-0.01±0.01	0.07±0.02 *	-0.01±0.01	0.01±0.01
4	0.00±0.00 *	0.04±0.01	0.07±0.03	0.08±0.01 *	0.03±0.01	0.07±0.02
5	0.01±0.01	0.05±0.00	0.08±0.03	0.04±0.01	0.03±0.01	0.08±0.03

Mean±SD (mm)

*Significant difference between PTN and PTU (p<0.05).

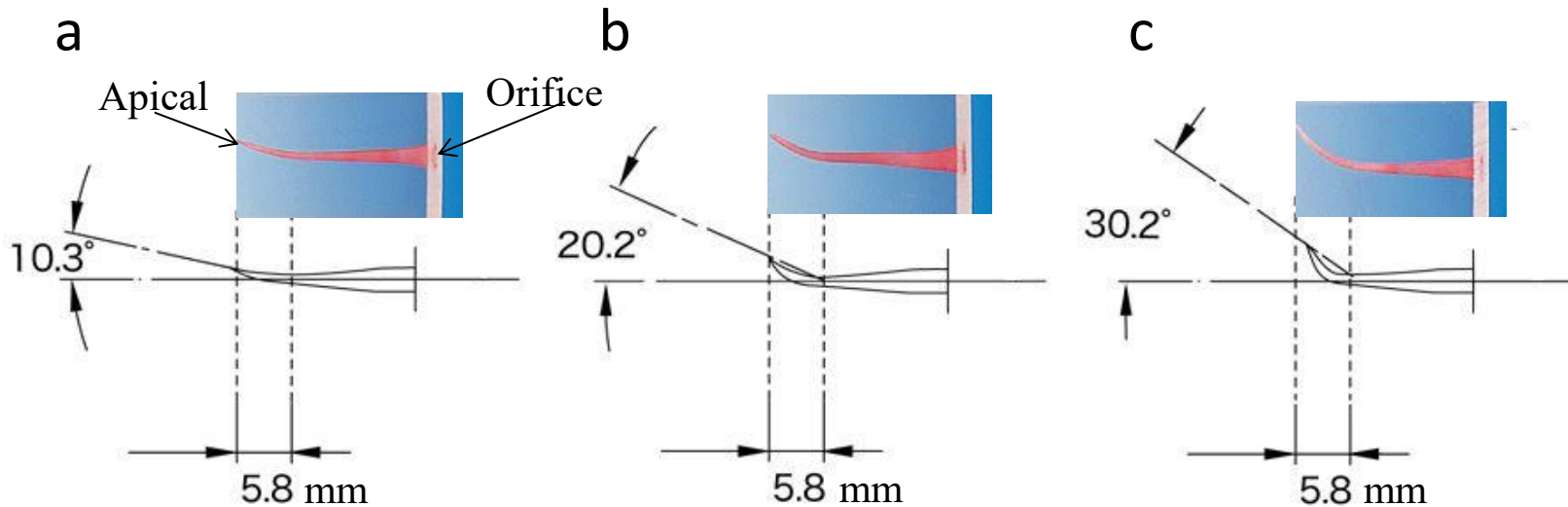


Figure 1. J - shaped canal blocks made of clear resin with apical diameter of 0.15 mm, taper of 06, and a 10° apical curvature (a), a 20° apical curvature (b), a 30° apical curvature (c).

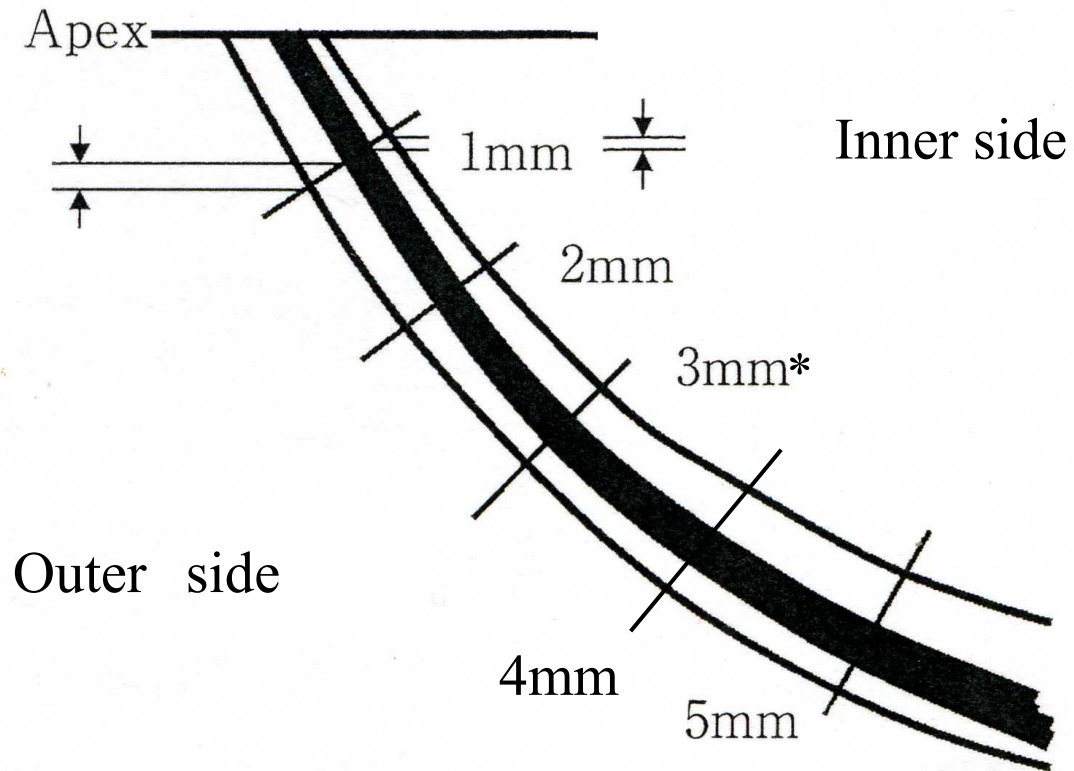


Figure 2. Pre-instrumentation and post-instrumentation images were superimposed and the difference between the canal configuration before and after instrumentation were measured in each one of the 5 traced levels

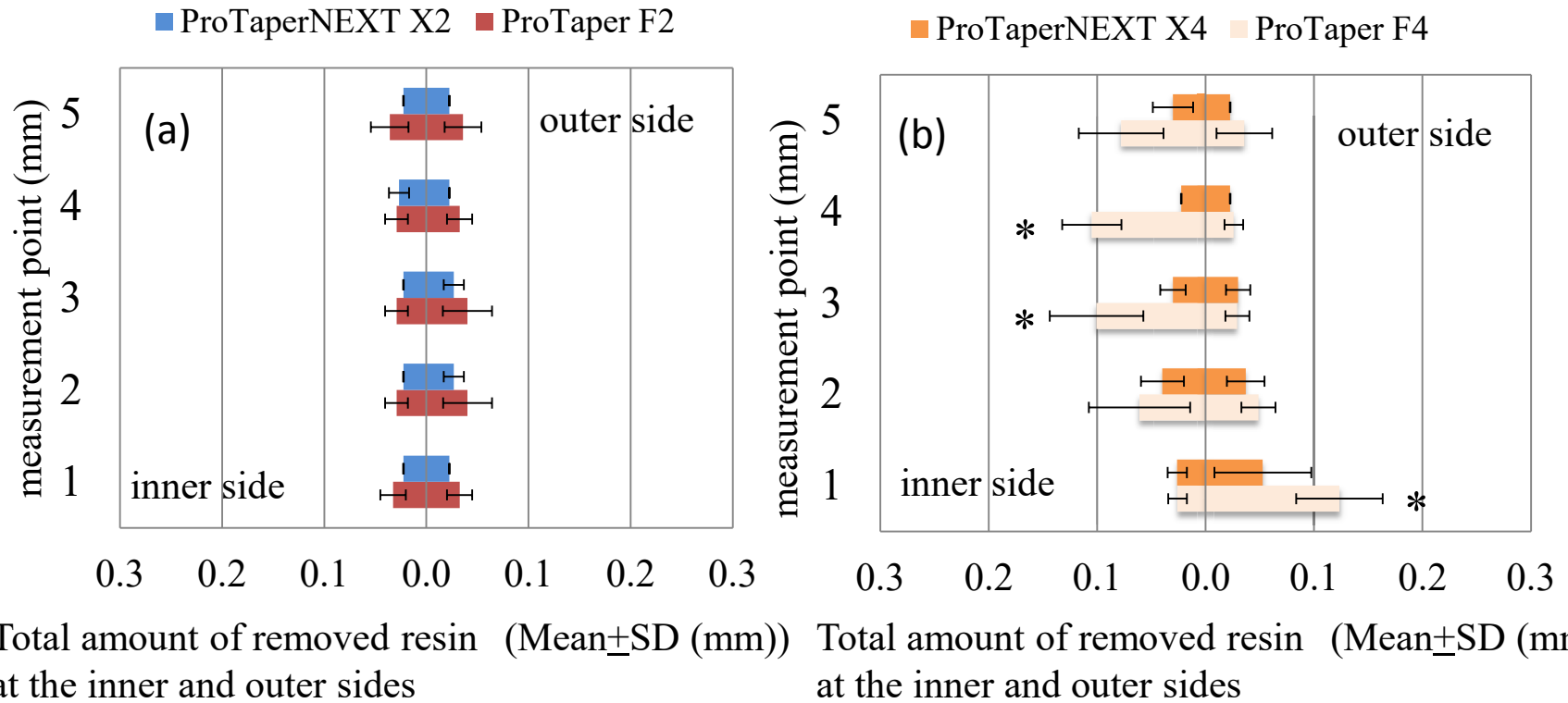
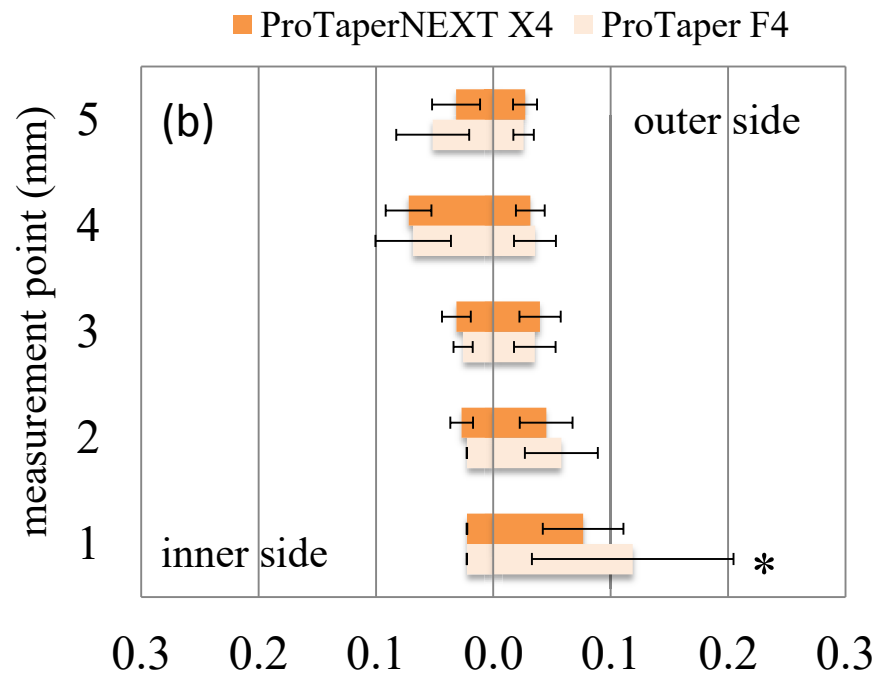
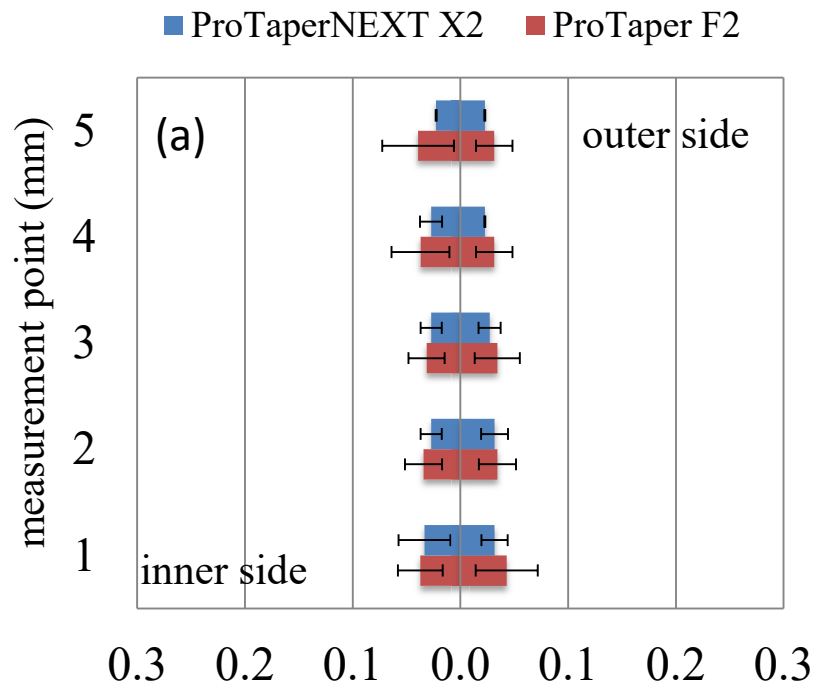


Figure 3. Total amount of removed resin (mm) at the different levels after root canal preparation for 10° apical curvature canals by (a) ISO #25 PTN, ISO #25 PTU, and (b) ISO #40 PTN, ISO #40 PTU. *Significant difference between PTN and PTU (p < 0.05)



Total amount of removed resin (Mean±SD (mm)) at the inner and outer sides

Total amount of removed resin (Mean±SD (mm)) at the inner and outer sides

Figure 4. Total amount of removed resin (mm) at the different levels after root canal preparation for 20° apical curvature canals by (a) ISO #25 PTN, ISO #25 PTU, and (b) ISO #40 PTN, ISO #40 PTU. * Significant difference between PTN and PTU (p<0.05)

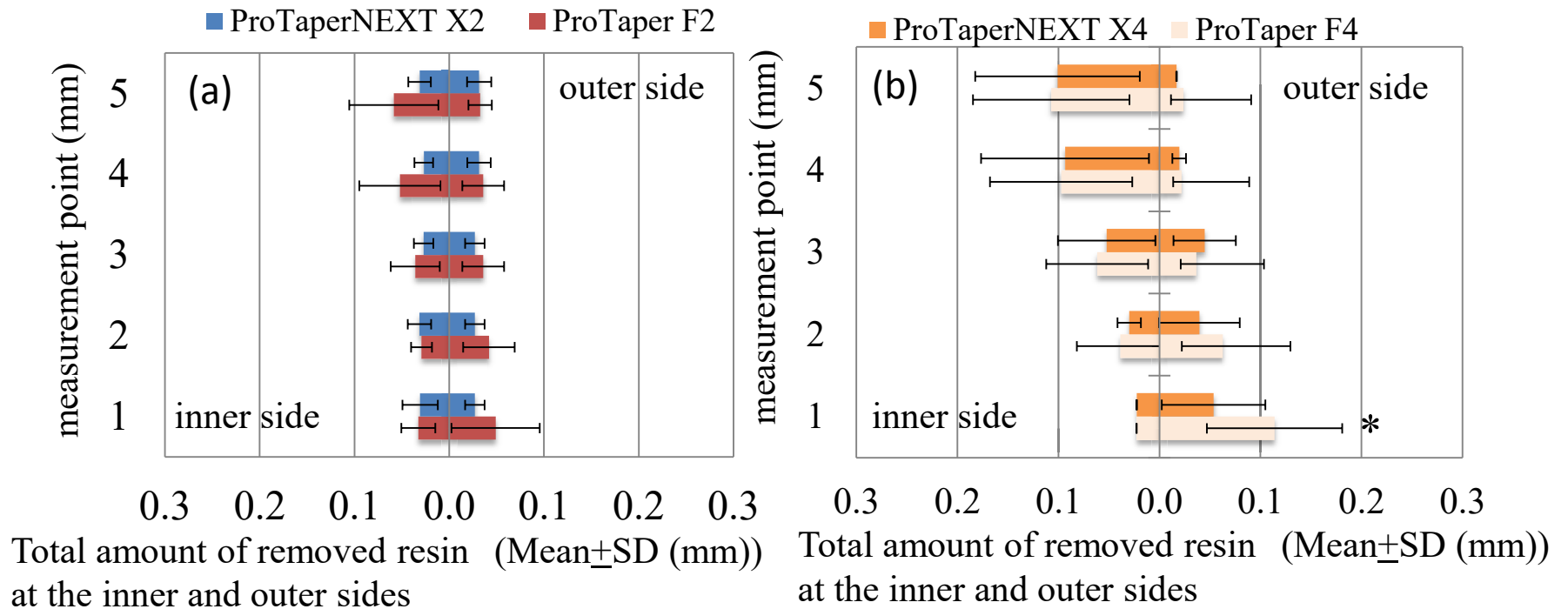


Figure 5. Total amount of removed resin (mm) at the different levels after root canal preparation for 30° apical curvature canals by (a) ISO #25 PTN, ISO #25 PTU, and (b) ISO #40 PTN, ISO #40 PTU. * Significant difference between PTN and PTU (p<0.05)