

## Shaping ability of Ni-Ti Rotary files in combination with GT Rotary Ni-Ti file

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국문초록

### GT Rotary Ni-Ti file과 함께 사용한 구동용 Ni-Ti file의 근관 성형력 비교에 대한 연구

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본 연구는 근관의 치관부는 GT Rotary file을 이용하여 성형하고, 근단부는 K-Flexofile, ProFile .04, Lightspeed, HERO642 file로 성형하여 근관용 file의 근관성형력을 비교하는 것이다. 실험 표본으로는 resin simulated root canal blocks(Dentsply, Swiss)를 이용하였고 4개의 군으로 분류하여 실험을 실시하였다. 모든 resin block을 GT Rotary file(Dentsply, Swiss)을 이용하여 치관부를 형성한 후 근단부는 K-Flexofile(Dentsply, Swiss), ProFile .04 taper file(Dentsply, Swiss), Lightspeed file(Lightspeed Tech., USA), HERO642 file(Micromega, France)로 ISO size #35까지 형성하였다. 성형 후 preparation time과 instrument failure를 측정하였고 최종 사용한 file을 resin block 내에 재위치시켜 working length의 변화량을 0.5mm 단위로 측정하였다. Resin debris에 의한 canal blockage를 조사하였으며, 근관 내의 인상을 채득하여 canal form을 평가하였다. 성형 전과 성형 후의 사진을 촬영하고 computer software를 이용하여 중첩시킨 후 canal aberration, canal transportation을 평가하여 다음과 같은 결과를 얻었다.

1. Preparation time, working length의 변화량, canal blockage, canal aberration, canal transportation에 있어서 Ni-Ti file이 stainless steel file에 비하여 우수하였다( $p < 0.05$ ). 반면에 근관성형력에 있어서 canal form과 canal transportation을 제외하고는 세 Ni-Ti file 사이에는 유의차가 없었다( $p > 0.05$ ).
2. Canal form 중 taper에 있어서 Lightspeed는 적절하지 못한 taper를 보여주었다( $p < 0.05$ ).
3. Canal transportation에 있어서 Lightspeed 군과 HERO642 군이 K-Flexofile 군과 ProFile .04 군에 비해 적게 나타났고( $p < 0.05$ ), 특히 만곡의 끝 부분에서는 Lightspeed 군이 가장 적게 나타났었다( $p < 0.05$ ).

이상과 같은 연구결과로 보아 부적절한 taper를 지니고 있던 Lightspeed file과 HERO642 file 중 HERO642 file은 GT Rotary file과 함께 사용함으로써 적절한 taper로 형성할 수 있었으나 Lightspeed file은 효과적이지 못하였으므로 적절한 taper를 형성하기 위한 file이 치근의 중간부를 형성하기 위해 필요함이 확인되었다.

### I. INTRODUCTION

Shaping of root canals is necessary to remove the microorganism and the pulp tissue and to facilitate obturation. The most appropriate canal shape for filling with gutta-percha and sealer is continuously tapering funnel shape with the smallest diameter at the end-point and the largest at orifice<sup>1)</sup>. Over the last 20 years or so

many endodontic instruments have been developed and numerous preparation techniques have been introduced, but few has been shown to achieve consistently the required funnel shape.

The inherent stiffness of stainless steel used in the manufacture of many endodontic instruments plays a part in the creation of aberration: this is further influenced by specific instrument design features and complexities in the canals<sup>2-4)</sup>.

Generally, preparation of narrow curved canals using stainless steel files is time consuming and difficult and limits the apical enlargement to relatively small sizes, which in turn reduces the efficacy of irrigation and hinders obturation.

A new generation of endodontic instruments has been developed recently from nickel-titanium that potentially allows shaping of narrow, curved root canal without causing aberration. Fabrication of endodontic files from nickel-titanium was investigated initially by Walia et al. (1988)<sup>6)</sup> who assessed the bending and torsional properties of K-type files. The nickel-titanium files were found to have two to three times the elastic flexibility of stainless steel files, due to the very low values of modulus of elasticity and showed superior resistance to torsional fracture, due to the ductility of the nickel-titanium<sup>6)</sup>. It was suggested that Nitinol files may be useful in the preparation of curved root canals<sup>6)</sup>.

Himel et al. (1995) evaluated stainless steel and Nitinol hand files using dental students to prepare two curved canals in resin blocks<sup>7)</sup>. Preparations by using Nitinol files were rated higher than preparations by using stainless steel files with significantly less zipping and ledging. Other reports have also confirmed the advantages of hand files made from nickel-titanium<sup>8,9)</sup>.

Several kinds of rotary nickel-titanium instruments have available. Their ability to maintain canal shape has been confirmed by many studies: they also have the advantage of being significantly faster than hand preparation<sup>8,9)</sup>.

Nickel-titanium instruments with increased taper have developed in the hope that the greater flare along the instrument shaft would create automatically the flare required in canal shape. The GT Rotary files are made of a series of four safe-ended instruments designed for canal preparation. Several features, such as the variably pitched flutes and fixed minimal and maximal flute diameters, are intended to encourage the mechanical objectives for root canal preparation. Each instrument has a different linear length of cutting blades, because the tapers vary between a fixed  $D_0$  diameter of 0.20mm and a maximal flute

diameter of 1.0mm. They incorporate instruments with .12 taper, .10 taper, .08 taper, .06 taper in ISO size 20<sup>10)</sup>.

The GT Rotary files and the ProFile .04 files share the same cross-sectional geometries and have three radial lands that each contains bidirectional cutting edges. The radial lands keep the instrument centered in the canal: their cutting edges are intended to scrape rather than actively engage and screw into dentin<sup>11)</sup>. The radial lands are separated by three U-shaped flutes that provide space for the accumulation of debris. The U-shaped configuration effectively augers debris coronally and out of the canal during clinical use. These files have a parallel core to enhance flexibility: their noncutting tips are designed to follow a pilot hole and guide the instrument through the canal preparation procedure. The recommended rotational speed for these instruments, regardless of the product line, is 150 to 300rpm<sup>8,12)</sup>. The ProFile .04 files are machined with safe-ended noncutting tips, increasing  $D_0$  diameter, and 16mm of cutting blades. The ProFile .04 series were initially the instrument line of choice for those colleagues who filled root canal systems using a carrier-based obturation technique.

An innovative approach to instrument design was described by Wildey and Senia<sup>13)</sup> who were responsible for the development of the SW instrument later to be marketed as the Canal Master. Studies of the Canal Master system have demonstrated the production of more rounded preparations compared with K-type files and less canal transportation.

Wildey et al. analyzed root canal instruments and commented that the material from which they were manufactured should be taken into account<sup>14)</sup>. This group of workers modified the flute design of the original Canal Master and produced the instrument in nickel-titanium creating the hand instrument, Ni-Ti Canal master "U". Subsequently, an engine driven version of the Ni-Ti Canal Master "U" design was modified to take advantage of the new nickel-titanium alloy and the Lightspeed instrument (Lightspeed Technology

Inc., San Antonio, TX) was evolved.

Glosson et al. compared the ability of hand and engine-driven nickel-titanium files to prepare curved canals in mandibular molars<sup>91</sup>. Lightspeed instruments performed significantly better than K-Flex or Mity hand file, producing more centered preparations with less transportation and less dentin removal in a significantly faster time. The apical transportation to curved root canals using Lightspeed instruments has also been assessed by Knowles et al. who found that apical transportation was present only in one of 20 teeth<sup>151</sup>.

The HERO 642 instrument are made from nickel-titanium and incorporate instruments with .06 taper, .04 taper, .02 taper in ISO sizes 20, 25, 30, with additional .02 tapers in sizes 35 and 40. They have a triple helix geometry, like that of the Helifile, with regular flutes from the apical end to the cervical part of the blade. It allows excellent coronal transport of debris without weakening the blade and the inner core remains maximal all along<sup>161</sup>.

The edge has been designed to offer a slightly positive cutting angle so that the instrument can cut like a curette shaping the canal wall. Thus the preparation will be achieved through the removal of successive dentinal chips. The positive angle at the cutting edge, plus the fact that there is no radical land, greatly reduce the friction on the canal wall and facilitate its release when overload. Futhermore, because of its triple-edged section, the instrument falls immediately centered into the canal, with an even distribution of the stress on the three cutting edges.

Finally, the blade is made with a progressive helix angle and pitch, from the apical tip to the cervical end, which limits the risk of screwing-in of the instrument: the operator can control the progression of the instrument and the preparation. The HERO 642 ISO tip at 60° is a continuation of the inner core, which makes it practically inactive, while maintaining its guiding effect.

The aim of this study was to compare the apical shaping ability of the ProFile .04 taper, Lightspeed and HERO 642 rotary instruments and to assess the combined effect of GT Rotary

**Table 1.** Instrument sequence with GT Rotary instruments

Sequence	1	2	3	4
File size	20/.12	20/.10	20/.08	20/.06
Preparation distance(mm)	10	12	14	16

files to Lightspeed and HERO 642 instruments.

## II . MATERIALS AND METHODS

### 1. Specimens and instruments

Forty-eight resin simulated root canal blocks (Endoblock, Maillefer, Swiss) were divided into 4 groups with 12 canals each. The entire block was 18mm long with the canal orifice 16mm from the simulated apex. The curvature started 10mm from the canal orifice. All canals had a mean curvature of 40 degrees, as determined by the Schneider method. The rotary instruments used in this study were GT Rotary file(Dentsply, Maillefer, Swiss), ProFile .04 file(Dentsply, Maillefer, Swiss), Lightspeed file(Lightspeed Tech., USA), HERO 642 file(Micromega, France) with ISO-sized tip and stainless steel K-Flexofile(Dentsply, Maillefer, Swiss).

### 2. Preparation of Simulated Resin Canals

Forty-eight blocks were prepared by one operator with GT Rotary files using a 16:1 high torque handpiece powered by an electric motor (Surgimotor II, Aseptico Co., USA) at 300rpm to the 16mm short of the apex. The instrument sequence for GT Rotary files is described in Table 1.

Thirty-six blocks in three experimental groups were prepared by one operator with ProFile .04 file, Lightspeed file and HERO 642 file using a 16:1 high torque handpiece powered by an electric motor. The same operator prepared twelve blocks as control with K-Flexofiles. All canals were prepared to a working distance of 18mm, and the size of final apical preparation was #35. Copious irrigation with water was performed

repeatedly after every instrument. During the preparation of the canals, each file was coated with glycerin to act as a lubricant. File were wiped regularly on a sponge to remove resin debris. During the instrumentation, apical patency filing and recapitulation were performed frequently with #10 K-Flexofiles. After instrumentation, all canals were dried with paper points.

1) Control Group(K-Flexofile Group)

Apical preparation was performed using stainless steel .02 taper K-Flexofiles. A #15 K-Flexofile was precurved before instrumentation and placed to the working length with a reciprocal and pull-out action until the apical portion of the canal was instrumented to #35.

2) ProFile .04 taper Group

ProFile .04 taper files of #20, 25, 30, 35 were sequentially used to the working length at 300 rpm.

3) Lightspeed Group

Lightspeed files of #20, 22.5, 25, 27.5, 30, 32.5, 35 were sequentially used to the working length at 1300 rpm.

4) HERO 642 Group

HERO 642 files were used at 300 rpm. The instrumentation sequence for HERO 642 instruments is described in Table 2.

3. Assessment of canal preparation

1) Preparation time

The time for canal preparation was recorded in minute and second and included file changes within the instrumentation sequence as well as irrigation.

2) Instrument failure

Instruments were examined after every use and the numbers of permanently deformed or fractured instruments were recorded, including the number of times the instruments had been used.

3) Loss of working distance

The final length of each canal was determined following preparation. The last using instrument was inserted into the prepared canal and its length within the canal measured to the nearest 0.5mm. Loss of working distance was determined by subtracting the final length from the original length(18mm).

4) Canal form

The internal three-dimensional shape of all canals was determined from intracanal impression. A small amount of Microfilm was introduced into the canal lumen to act as a lubricant. Light bodied vinyl polysiloxane impression material (Zerosil, DREVE, Germany) was carefully injected into each canal orifice, followed by the introduction of a fine barbed broach, to act as support for the coronal part of the impression and to facilitate removal.

The impressions of the prepared canals were removed and assessed under magnification using the following criteria<sup>17)</sup>.

*Apical stop*

Categorized as absent, present (but poorly defined) or present (well defined).

*Smoothness of apical half of the canal*

Categorized as poor or good.

*Flow*

Good flow characteristics were defined as a con-

**Table 2.** Instrument sequence with HERO 642 instruments

Sequence	1	2	3	4	5	6
File size	20/.04	25/.06	25/.04	30/.06	30/.04	35/.02
Preparation distance(mm)	18	16	18	16	18	18

tinuous blending of the canal from orifice to apical stop. Abrupt changes in direction and presence of ledges gave rise to poor flow characteristics.

#### *Taper*

This was categorized as good when the canal had a conical shape throughout its length. Canals with poor taper had hourglass or cylindrical shapes.

#### 5) Canal aberration and transportation

Aberration and transportation of prepared canals were assessed using Photoshop 5.5 (Adobe, USA). Images of pre- and postoperative resin canals were taken using a digital camera. Superimposition of pre- and postoperative images of all canals was aided by three orientation holes placed in the sides of resin blocks. Assessments were made according to the presence and position of transportation and several types of canal aberration, such as apical zip, elbow, ledge and perforation.

#### *Apical zip*

Defined as an irregular widened area created by master apical file near the end-point preparation where resin had been removed excessively from the outer aspect of the canal.

#### *Elbows*

These occurred concurrently with an apical zip and formed a narrower region, more coronally.

#### *Ledges*

These were present when an irregular area of resin was removed from the outer aspect of the curved portion of the canal not associated with a preparation at the end always associated with a narrow region more coronally.

#### *Perforations*

These occurred as separate and distinct false canals toward the end-point, along the outer aspect of the curve, not confluent with the original canal.

#### *Directions of transportation*

The direction of canal transportation of apical portion was determined as the inner, outer and none.

#### 4. Recording, storage and analysis of data

Data was recorded directly on cording sheet and then stored in a PC. Following error and range check, the data were analysed using Winks 4.1c (Texassoft Inc., USA), an interactive statistics package. One-way ANOVA/Turkey's analysis was used to determine significant difference at the 95% level.

### III. RESULTS

#### 1. Preparation time

The mean time to prepare 48 canals with GT Rotary files was  $4.25 \pm 0.44$  minutes. The mean instrumentation time to prepare the canals is shown in Table 3. There were no significant differences among the three rotary instrumentation groups ( $p > 0.05$ ), but K-Flexofile Group took significantly more time than the other three rotary groups ( $p < 0.05$ ).

#### 2. Instrument failure

The number of fractured and deformed instrument is shown Table 4. One size 35 instrument, two size 30 instruments and one size 25 instrument were fractured and one size 20 instrument was deformed in ProFile .04 taper group. One size 35 instrument and one size 32.5 instrument were fractured in Lightspeed group. Three size 20 instruments were deformed in HERO 642 group.

#### 3. Change of working distance

The mean loss of working distance is shown in Table 5. The K-Flexofile group was  $-1.04 \pm 0.75$ mm, ProFile .04 taper group;  $-0.12 \pm 0.23$ mm, Lightspeed group;  $-0.04 \pm 0.14$ mm; HERO 642 group;  $-0.12 \pm 0.23$ mm. Significantly

**Table 3.** Mean operation time, in minute, by instrumentation techniques (Average±S.D.)

Group	K-Flexofile	ProFile .04	Lightspeed	HERO642
Preparation time	8.32±0.71*	3.87±0.43	4.32±0.37	4.17±0.50

\*ANOVA/Turkey's analysis, significance  $p < 0.05$

**Table 4.** Incidence of instrument failure(fracture, deform) by instrumentation techniques

Group	K-Flexofile	ProFile .04	Lightspeed	HERO 642
Fracture	0	4	2	0
Deform	0	1	0	3
Total	0	5	2	3

**Table 5.** Loss of working distance in millimeter by instrumentation techniques

Group	K-Flexofile*	ProFile .04	Lightspeed	HERO 642
Mean change	-1.04±0.75	-0.12±0.23	-0.04±0.14	-0.12±0.23

\*ANOVA/Turkey's analysis, significance  $p < 0.05$

more loss of working distance took place in K-Flexofile group, compared with the other three rotary techniques( $p < 0.05$ ).

#### 4. Canal blockage

Five canals were blocked in only K-Flexofile group but the other canals remained patent following preparation.

#### 5. Canal form

##### *Apical stop*

The quality for apical stops is detailed in Table 6. No canal was well defined in K-Flexofile group.

##### *Apical smoothness*

All canals, except five canals in K-Flexofile group, had smooth apical canal walls.

##### *Flow*

Flow characteristics are shown in Table 7. Seven canals exhibited poor flow characteristics in K-Flexofile group, there were significant differences( $p < 0.05$ ) between instruments in terms of

the flow.

##### *Taper*

The general taper characteristics of the prepared canals are shown in Table 8. All of the canals exhibited poor taper in Lightspeed group, there were significant differences( $p < 0.05$ ) between instruments in terms of the taper.

#### 6. Canal aberration

The results are summarized in Table 9.

##### *Zip/Elbow*

Only one zip and elbow were created in the rotary instrumentation groups: ProFile .04 taper group(Fig. 1). There were no significant differences among the three rotary instruments, but significantly more zips and elbows were created in the K-Flexofile group( $p < 0.05$ ).

##### *Ledge, Perforation*

A total of three ledges and no perforation were created in the rotary instrumentation groups: one was in the ProFile .04 taper group and the other

**Table 6.** Assessment of apical stops from intracanal impression

Group	K-Flexofile	ProFile .04	Lightspeed	HERO 642
Good	0	4	2	6
Poor	10	6	9	3
Absent	2	2	1	3

**Table 7.** Canal flow characteristics by instrumentation techniques

Group	K-Flexofile*	ProFile .04	Lightspeed	HERO 642
Good	5	11	12	10
Poor	7	1	0	2

\*ANOVA/Turkey's analysis, significance  $p < 0.05$

**Table 8.** Canal taper characteristics by instrumentation techniques

Group	K-Flexofile	ProFile .04	Lightspeed*	HERO 642
Good	11	12	0	12
Poor	1	0	12	0

\*ANOVA/Turkey's analysis, significance  $p < 0.05$

**Table 9.** Incidence of canal aberrations by instrumentation techniques

Group	K-Flexofile	ProFile .04	Lightspeed	HERO 642
Zip/elbow	6*	1	0	0
Ledge	4	1	0	2
Perforation	1	0	0	0

\*ANOVA/Turkey's analysis, significance  $p < 0.05$

**Table 10.** Incidence of canal transportations by instrumentation techniques

Group	K-Flexofile			ProFile .04			Lightspeed			HERO 642		
	inner	none	outer	inner	none	outer	inner	none	outer	inner	none	outer
End point	0	0 <sup>a</sup>	12	0	3 <sup>a,b</sup>	9	0	7 <sup>b,c</sup>	5	0	9 <sup>c,d</sup>	3
Apex of curve	0	0	12	0	1	11	0	6*	6	0	3	9
Beginning of curve	11	1	0	8	4	0	7	4	1	8	4	0

\*ANOVA/Turkey's analysis, significance  $p < 0.05$

Figure with the same letter, no significant  $p > 0.05$ .

were in the HERO 642 group(Fig 7. Direction of transportation

2). There were no significant differences between all three rotary groups( $p > 0.05$ ). One perforation was created in the K-Flexofile group.

## 7. Direction of transportation

The result summarized in Table 10.

At the end-point of preparation, nine canals in the HERO 642 group remained centered and this is the highest number in the four groups.

At the apex of the curve, six canals in the Lightspeed group remained centered and this is the highest number in the four groups. There were significantly more canal centering among the three rotary instrumentation group ( $p < 0.05$ ).

All of the canal at the end-point and the apex of curve were transported to outer aspects (Fig. 3).

## IV. DISCUSSION

This study evaluated apical shaping ability of the ProFile .04 taper file, the Lightspeed file and the HERO 642 file and the combined effect of high taper GT Rotary file to the Lightspeed file and HERO 642 file in the resin simulated canals. The combined effect of high taper GT Rotary file to the ProFile .04 taper file has been previously shown but there were few studies about the combined effect to the Lightspeed file and HERO 642 file<sup>18</sup>.

The apical preparation size chosen was equivalent to ISO #35 as it has been previously shown that a large apical instrumentation size more predictably cleaned the canal<sup>19</sup>. Reproducibility was secured by three orientation holes within the resin blocks to ensure the relocation could be safely achieved.

To assess instrumentation of curved canals, clear resin blocks were used in this study. These were chosen because shape, size, taper and curvature of the canal are standardized. Lim et al. have validated the credibility of a resin block as an ideal experimental model for the quantitative and qualitative analyses of endodontic preparation<sup>20</sup>. Used for the study of rotary instruments, however, the resin material is not ideal because it does not cut in the same way as dentin. Many rotary instruments do not have sharp cutting edge, but remove dentin by a grinding action. The effect of this grinding action in resin is unknown,

but heat generated may sometimes soften the resin material. Nevertheless for a study like that it is the only material presently available, and it is very useful if the results are properly interpreted.

Thompson et al. reported shaping ability of the ProFile .04 taper files, the Lightspeed files and the HERO 642 files in the simulated root canals<sup>21-26</sup>. The ProFile .04 taper instruments involved eight instruments change, the Lightspeed instruments; twenty-two, the HERO 642; ten instruments change in their study. In this study, the ProFile .04 taper group involved seven instruments change, the Lightspeed group; eleven, the HERO 642 group; ten instruments change.

The preparation time noted in this study was least in the ProFile .04 taper group, which involved fewer instruments change, compared with the other rotary instrument groups. However the mean instrumentation time was not significantly different among the three rotary groups. Clearly the nickel-titanium instrumentation has the potential to speed up canal preparation, compares with hand instruments.

It is important in the root canal therapy to control the working length to avoid over- and under-extension of preparation. In this study the mean change of working length in the three rotary groups was less than that of K-Filexoflex group.

Our results for an assessment of canal aberrations showed that there were no significant differences in the incidence of canal aberrations among the three rotary instrumentation groups. No zip, elbow or ledge was created during preparation to suggest that Lightspeed instruments were able to negotiate and prepare at the end-point even those canals with severe acute curves.

Thompson et al. reported that Lightspeed instruments and HERO 642 instruments produced canals with poor taper characteristics<sup>23,25</sup>. The lack of taper is reflection of the instrument design and sequence of instrumentation in the Lightspeed instruments. The HERO 642 instruments produced canals with poor taper characteristics which presumably reflected the use of standard .02 tapered files. In our study, HERO 642



group produced canals with good taper characteristics which presumably reflected the use of high taper GT Rotary files and the use of .06 tapered files with 16mm preparation distance but the Lightspeed group produced canals with poor taper characteristics.

## V. CONCLUSION

Shaping of root canals is necessary to facilitate obturation. The most appropriate canal shape for filling with gutta-percha and sealer is continuously tapering funnel shape with smallest diameter at the end-point and largest at orifice. The aim of this study was to compare the apical shaping ability of the ProFile .04 taper, Lightspeed and HERO 642 rotary instruments and to assess the combined effect of GT Rotary files to Lightspeed and HERO 642 instruments.

From the result of this study, it can be concluded as follows :

1. The K-Flexofile group was significantly more than the three rotary instruments groups in preparation time, change of working distance, canal blockage and canal aberration( $p < 0.05$ ). On the other hand, there were no significant differences among the three rotary instruments groups in shaping ability except for canal form and transportation.
2. The Lightspeed group produced significantly more canals with the poor taper characteristics than the other instruments groups ( $p < 0.05$ ).
3. The Lightspeed group and the HERO 642 group were significantly less transported than the other instruments group at the end-point. At the apex of curve, the Lightspeed group was significantly less transported than the other instruments groups ( $p < 0.05$ ).

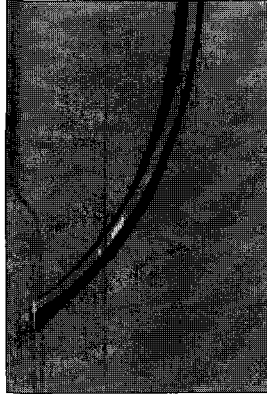
This study suggests that the use of additional tapered files to prepare the middle part of the root canal is helpful for the adequate tapered canal shaping in the Lightspeed system combined with GT rotary files.

## REFERENCE

1. Schilder H: Cleaning and shaping of the root canal, Dent Clin North Am, 18:269-96, 1974.
2. Eldees ME, Boraas JC: The effect of different files on the preparation shape of severely curved canal, Int Endod J, 18:1-7, 1995.
3. Al-Omari MAO, Dummer PMH: Comparison of six files to prepare simulated root canals. Part 1, Int Endod J, 25:57-66, 1992.
4. Al-Omari MAO, Dummer PMH: Comparison of six files to prepare simulated root canals. Part 2, Int Endod J, 25:67-81, 1992.
5. Schafer E, Tepel J, Hoppe W: Properties of endodontic hand instruments used in rotary motion. Part 2. instrumentation of curved canals, J Endodon, 21:240-6, 1995.
6. Walia H, Brantley WA, Gerstein H: An initial investigation of the bending and torsional properties of Nitinol root canal files, J Endodon, 14:346-57, 1988.
7. Himel VT, Ahmed KM, Wood DM, Alhadainy HA: An evaluation Nitinol and stainless steel files used by dental students during a laboratory proficiency exam, Oral Surg Oral Med Oral Pathol, 79:232-7, 1995.
8. Espisito PT, Cunningham CJ: A comparison of canal preparation with nickel-titanium and stainless steel instruments, J Endodon, 21:173-6, 1995.
9. Glosson CR, Haller RH, Dove SB, del Rio CE: A comparison of root canal preparation using Ni-Ti hand, Ni-Ti engine-driven and K-Flex endodontic instruments, J Endodon, 21:146-51, 1995.
10. Clifford J: Cleaning and shaping the root canal system, Pathways of the pulp. 7th edn. St Louis. MO. USA. The CV Mosby Company. 253. 2000.
11. Blum JY, Cohen AG, Machtou P, Micallef JP: Location of contact areas of ProFile NiTi rotary instruments in relation to the forces developed during mechanical preparation of extracted teeth, Int Endod J, 32(2):108-14, 1999.
12. Miserendino LJ, Moser JB, Heuer MA, Osetek EM: Cutting efficiency of endodontic instruments. I. Analysis of tip design, J Endod, 12(1):8-12, 1986.
13. Wildey WL, Senia ES: A new root canal instrument and instrumentation technique: a preliminary report, Oral Surg Oral Med Oral Pathol, 67:198-207, 1989.
14. Wildey WL, Senia ES, Montgomery S: Another look at root canal instrumentation, Oral Surg Oral Med Oral Pathol, 74:499-507, 1992.
15. Knowles KI, Ibarrola JL, Christiansen RK: Assessing apical deformation and transportation following the use of Lightspeed root canal instruments, Int Endod J, 29:113-7, 1996.
16. Vulcain JM, Calas P: The three wave concept of HERO 642, Endod Pract, 2(2):20-30, 1999.
17. Abou-Rass M, Jastrab RJ: The use of rotary instruments as auxiliary aids to root canal preparation of molars, J Endod, 8:78-82, 1982.
18. Kum KY, Spangberg L, Cha BY et al: Shaping ability of three ProFile rotary instrumentation techniques in the simulated resin root canals, J Endod, 12:719-23, 2000.
19. Kanavagh D, Lumley PJ: An in vitro evaluation of canal preparation using ProFile .04 and .06 taper series instruments, Endod Dent Traumatol, 14:16-24,

- 1998.
20. Lim SS, Webber J: The validity of simulated root canals for the investigation of the prepared root canal shape, *Int Endod J*, 18:240-6, 1985.
  21. Thompson SA, Dummer PMH: Shaping ability of ProFile .04 taper series 29 rotary nickel-titanium instruments in simulated root canals. Part 1, *Int Endod J*, 30:1-7, 1997.
  22. Thompson SA, Dummer PMH: Shaping ability of ProFile .04 taper series 29 rotary nickel-titanium instruments in simulated root canals. Part 2, *Int Endod J*, 30:8-15, 1997.
  23. Thompson SA, Dummer PMH: Shaping ability of Lightspeed rotary nickel-titanium instruments in simulated root canals. Part 1, *J Endod*, 23:698- 702, 1997.
  24. Thompson SA, Dummer PMH: Shaping ability of Lightspeed rotary nickel-titanium instruments in simulated root canals. Part 2, *J Endod*, 23:742-7, 1997.
  25. Thompson SA, Dummer PMH: Shaping ability of HERO 642 rotary nickel-titanium instruments in simulated root canals. Part 1, *Int Endod J*, 33:248-54, 2000.
  26. Thompson SA, Dummer PMH: Shaping ability of HERO 642 rotary nickel-titanium instruments in simulated root canals. Part 2, *Int Endod J*, 33:255 -61, 2000.

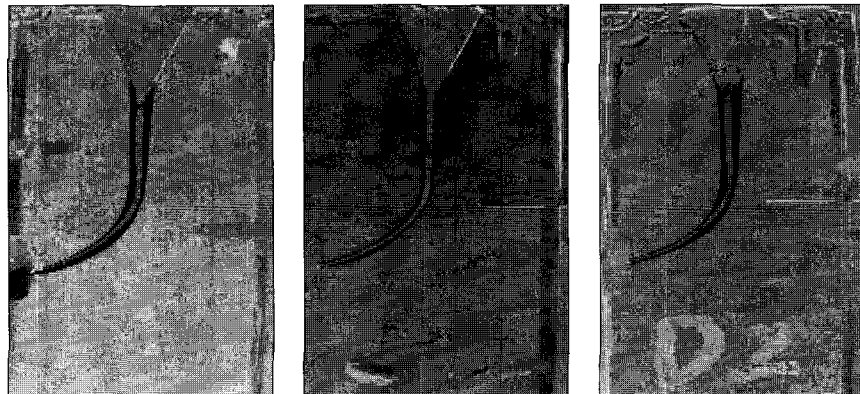
### Explanation of Figures



**Fig. 1.** Composite image of the simulated root canal with apical zip and elbow in the ProFile .04 taper instrument.



**Fig. 2.** Composite image of the simulated root canal with ledge in the HERO 642 instrument.



**Fig. 3.** Composite image of the simulated root canal in the ProFile .04, Lightspeed, HERO 642 instruments.