# The Self-adjusting File (SAF). Part 1: Respecting the Root Canal Anatomy—A New Concept of Endodontic Files and Its Implementation

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## Abstract

**Aim:** To introduce a new concept, the self-adjusting file (SAF), and discuss its unique features compared with current rotary nickel-titanium file systems. **The New Concept:** The SAF file is hollow and designed as a thin cylindrical nickel-titanium lattice that adapts to the cross-section of the root canal. A single file is used throughout the procedure. It is inserted into a path initially prepared by a # 20 K-file and operated with a transline- (in-and-out) vibration. The resulting circumferential pressure allows the file's abrasive surface to gradually remove a thin uniform hard-tissue layer from the entire root canal surface, resulting in a canal with a similar cross-section but of larger dimensions. This holds also for canals with an oval or flat cross-section, which will be enlarged to a flat or oval cross-section of larger dimensions. The straightening of curved canals is also reduced because of the high pliability of the file and the absence of a rigid metal core. Thus, the original shape of the root canal is respected both longitudinally and in cross-section. The hollow SAF file is operated with a constant flow of irrigant that enters the full length of the canal and that is activated by the vibration and is replaced continuously throughout the procedure. This results in effective cleaning even at the cul de sac apical part of the canal. The SAF has high mechanical endurance; file separation does not occur; and mechanical failure, if it occurs, is limited to small tears in the latticework. **Conclusion:** The SAF represents a new step forward in endodontic file development that may overcome many of the shortcomings of current rotary nickel-titanium file systems. *(J Endod 2010;36:679–690)*

## Key Words

Canal preparation, curved root canals, endodontic files, flat root canals, micro–computed tomography scan, nickel-titanium, SAF, scanning electron microscopy, self-adjusting file

The cleaning and shaping of the root canal is the key step in root canal treatment. Its aim is to remove all tissue debris from the root canal space while removing the inner layers of root canal dentin (1). For many years, it has been a common practice to enlarge the root canal to at least three ISO sizes larger than the first file to bind at the apical part of the canal (2, 3). It was assumed that such preparation will remove the inner layers of the dentin while allowing the irrigant to reach the entire length of the root canal for a thorough cleaning and disinfection of the root canal space (4, 5). This goal is easier to achieve today, even in curved root canals, because of the introduction and use of rotary nickel-titanium file systems. Because of their elasticity, these files can preserve the location of the root canal axis, thus largely preventing its transportation and ledging, which were major problems with stainless steel hand files. Rotary nickel-titanium files do this more efficiently and apparently require less operator expertise. The resulting root canal filling radiographs are impressive, yet the third dimension of the root canal is commonly ignored (6).

The goal of cleaning and shaping may be easily and reproducibly achieved with rotary files as far as relatively straight and narrow root canals with a round cross-section are concerned. In such canals, completion of the file sequence may result in a clean canal with no tissue debris and with removal of all or most of the inner layer of the heavily contaminated dentin. Nevertheless, in flat oval-shaped root canals and in curved ones, this goal is not easy attainable (7, 8).

Flat oval root canals are common in the distal roots of lower molars, upper and lower bicuspids, and lower incisors and canines. Asymmetrical, flat, tear-shaped cross-sections are another challenge. Such canals are common in most roots that contain two root canals in the same root and a potential isthmus. This includes anterior roots of lower molars, mesiobuccal roots of upper molars, first upper bicuspids, and some lower incisors. A systematic and comprehensive study by Wu et al (9) has shown that oval or flat root canal morphology is present in up to 25% of root canals, and in certain root groups it may exceed 50%. The flatness or asymmetry in these canals is usually in the buccolingual dimension; therefore, it fails to be recognized on clinical radiographs, which represent a buccolingual projection (Fig. 1).

The buccal and lingual areas of such flat root canals and the area facing the isthmus in tear-shaped ones cannot be adequately prepared by current rotary files. All current rotary files have one or another type of spiral blade and helical formation that when rotating machines the root canal into a form that has a round cross-section. Substantial untouched areas may be left on the buccal and lingual sides of a flat root

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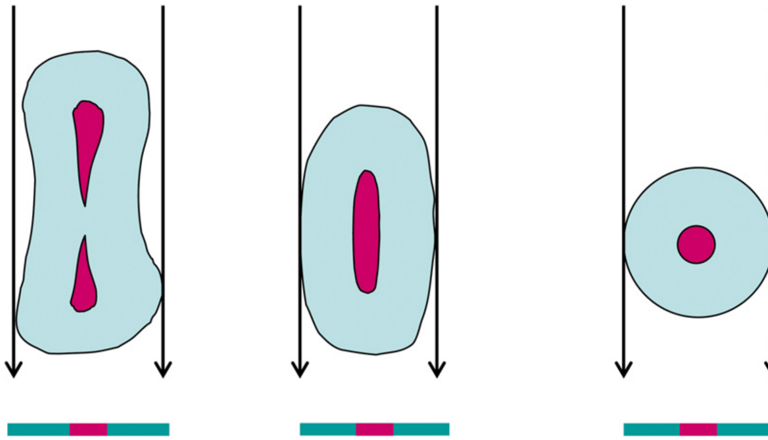

**Figure 1.** The limited value of two-dimensional radiographs. All three root canal cross-sections look the same on buccolingual projection radiographs.

canal or on the side facing the isthmus in tear-shaped ones (Fig. 2). A similar problem has been shown by Wu et al (7, 8) with hand files.

Current technology may mislead the operator to believe that the canal has been adequately shaped when, in fact, recesses full of infected tissue and debris may have been left on the buccal and/or lingual sides of the area prepared by the rotary file (Fig. 3A). Furthermore, such root canals may never be adequately obturated and sealed because the root canal filling or even the sealer will be separated from the canal wall by

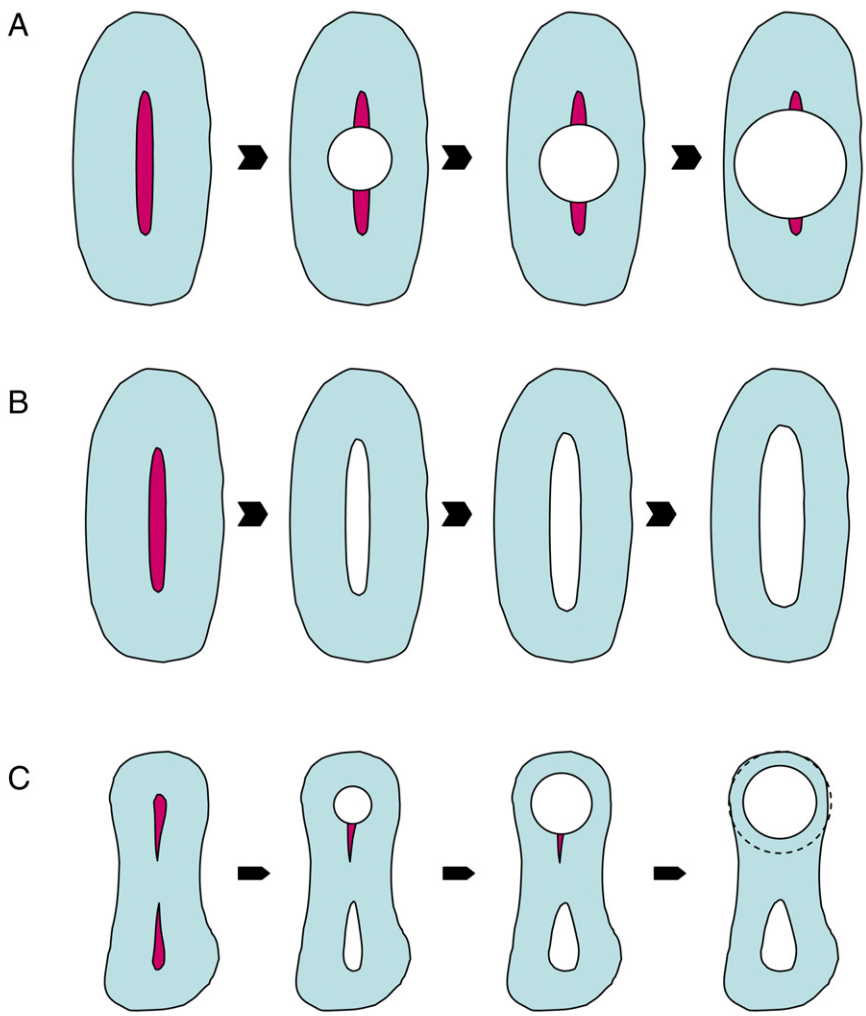


**Figure 2.** Schematic cross-sections of flat and tear-shaped root canals. Preparation with rotary files alone cannot adequately clean the (*A*) flat or (*upper part of C*) tear-shaped canals. Attempts to use larger instruments to include the whole cross-section may lead to localized thinning of the remaining dentinal wall. (*B* and *lower part of C*) The SAF enlarges the canal to the same shape with bigger dimensions.

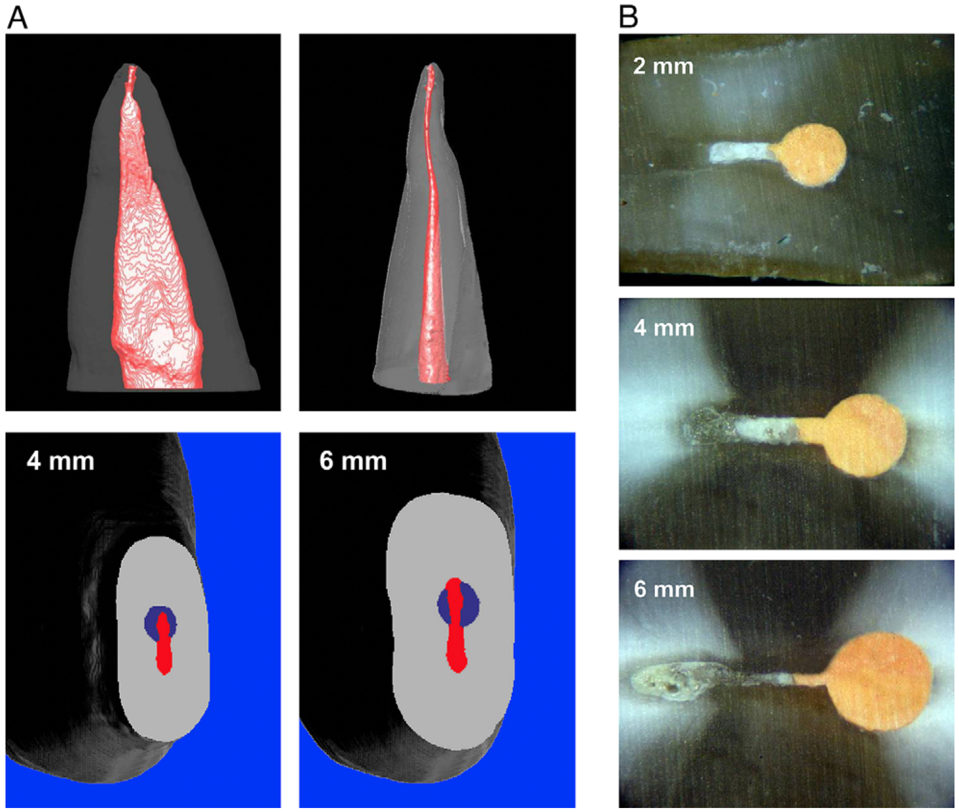


**Figure 3.** (*A*) A flat root canal prepared with a rotary file. (*Top*) Buccal and mesial views of the root canal before treatment. (*Bottom*) Cross-sections at 4 and 6 mm from the apex. A micro-CT analysis. Red, before; blue, after. (*B*) Obturation of a flat root canal prepared by rotary files. The root canal of a maxillary premolar prepared with rotary files and obturated with warm gutta-percha and AH-26 sealer (Dentsply-DeTrey, Konstanz, Germany). Cross-sections at 2, 4, and 6 mm from the apex. Note the untreated recess full of debris that prevented the flow of the gutta-percha and sealer.

the remaining tissue and debris (Fig. 3*B*), providing a potential space for bacterial growth and/or future recontamination of the root canal with bacteria. Furthermore, the operator may not be aware that anything went wrong because the root canal filling may look satisfactory on the x-ray.

The results of cleaning and shaping with rotary instruments are no better with curved root canals. When the three-dimensional shape of root canals was studied using micro–computed tomography (CT) scans, rotary nickel-titanium files failed to adequately and reproducibly prepare all the inner surfaces of curved canals, such as those of maxillary molars (Fig. 4) (10). Peters et al (10) found that when upper molars were prepared with rotary files 43% $\pm$ 29% and 33% $\pm$ 19% of the wall of the mesiobuccal and distobuccal canals remained unchanged, respectively. The results were no better even in the larger palatal canal, which is commonly thought to be easier to clean and shape. Rotary nickel-titanium files left 49% $\pm$ 29% of the canal surface unchanged. Furthermore, the extremely high standard deviation indicates the high variability of the results; some may have been better, but some were much worse.

A clinician cannot predict what will be the result in any given canal anatomy. This is because of two inherent problems: one macroscopic and the other microscopic. Macroscopically, the palatal roots of the upper molars are frequently curved buccally, a dimension not seen in clinical radiographs. Microscopically, the discrepancies revealed by micro-CT scans at a resolution of 36 $\mu$m, as done in the previously mentioned study (10), are hardly detectable by the human eye; nevertheless, they are large relative to the size of the bacteria that might penetrate them ($\sim$1 $\mu$m).

Another inherent problem with rotary-nickel titanium files is apical canal transportation in curved root canals (5, 10). Most file systems will adequately maintain the apical part of a curved root canal in place as far as the thin instruments are concerned. However, the larger-diameter instruments are relatively stiffer and have a tendency to remove more dentin on the outer side of the curvature of the apical area, leading to apical canal transportation (5, 10, 11). Rotary file manufacturers made many improvements, such as noncutting tips and more flexible alloys and designs, but the problem still exists. Therefore, the instructions for use usually indicate that the thicker instruments should not be applied in the apical part of a curved canal more than the absolute minimum time required for them to reach the working length; otherwise, apical canal transportation may occur (5).

Transportation of the canal at this critical point can have two major drawbacks: first, the apical part of the canal on the inner side of the curvature may remain untouched and full of debris, and, second, it may lead to ledging or even a subsequent perforation. To date, most if not all file systems have this inherent problem to one extent or another (11–13).

Another closely related problem is straightening of the root canal at the midroot section of curved root canals. Most file systems will straighten this part of the curvature to one extent or another by removing more dentin on the inner side of the curvature (10). This may reduce the thickness of the remaining dentin on the inner side of the curvature to such an extent that it increases the risk of vertical root fracture (14) or even results in a strip perforation.

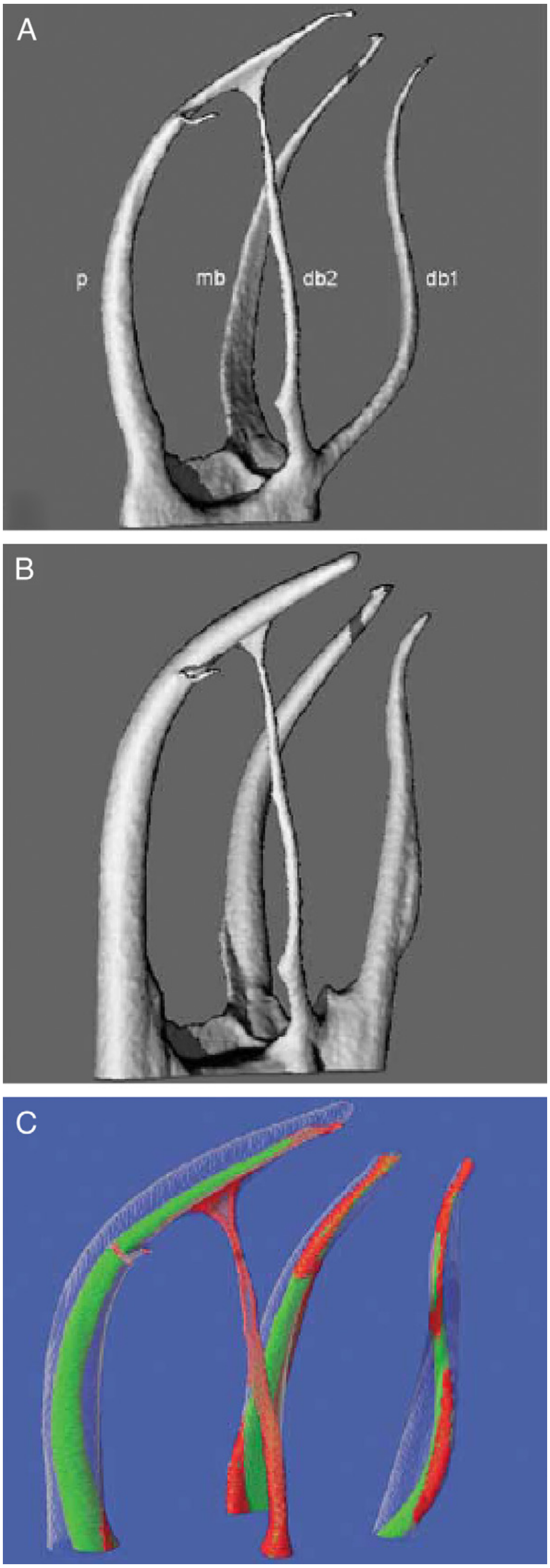


**Figure 4.** Micro-CT analysis of preparation of curved root canals using rotary nickel-titanium files. (*A*) Before, (*B*) after, and (*C*) three-dimensional analysis. Clear, prepared canal; green, affected surface; red, surface unchanged by the file. Reproduced with permission from Peters OA, Peters CI, Schönenberger K, et al. ProTaper rotary root canal preparation: effects of root canal anatomy on final shape analyzed by micro CT. Int Endod J 2003;36:86-92.

Accurate length measurement is an essential prerequisite for the use of any rotary file. The thin nickel-titanium rotary files are extremely flexible and may negotiate even a canal with a rather sharp apical curve. When a rotary file accidentally passes the apical foramen of such a curved canal, because of either misleading length measurement or failure to keep the marker on the file in place, it may soon lacerate or zip the apical foramen and form an oval opening with potential loss of the apical constriction. This may turn a simple root canal anatomy into a more complex one that is more difficult to handle. Slipping of the master cone beyond the apex during lateral condensation or extrusion of heat-softened gutta-percha may be one of the results.

Unexpected separation of rotary nickel titanium files was and still is the major drawback. Improvements in metallurgy, design, surface treatment, quality control, and, above all, the introduction of hands-on training, have significantly reduced the extent of this problem, nevertheless it is still with us. As opposed to stainless steel files that may give a "warning" by some distortion that appears in an abused file, usually no such macroscopic sign will appear in a rotary nickel titanium file. Furthermore, even in the era of microscope-assisted root canal treatment, a separated nickel-titanium file screwed in at the apical part of an even slightly curved canal is much more difficult to remove than a similar segment of a stainless steel file.

Rotary nickel-titanium files have been a great step forward in modern root canal treatment. They allow efficient shaping in curved canals that were hardly negotiable before while reasonably maintaining their original long axis in its original position. Nevertheless, to overcome the inherent remaining problems of the nickel-titanium instruments, a new concept in cleaning and shaping is warranted; hence, the self-adjusting file (SAF) was developed.

# The SAF

## Design and Mode of Operation

The SAF is a hollow file designed as a compressible, thin-walled pointed cylinder either 1.5 or 2.0 mm in diameter composed of 120-$\mu$m-thick nickel-titanium lattice (Fig. 5*A*). The 1.5-mm file may easily be compressed to the extent of being inserted into any canal previously prepared or negotiated with a # 20 K-file (Fig. 5*B*) (15). The 2.0-mm file will easily compress into a canal that was prepared with a #30 K-file. The file will then attempt to regain its original dimensions, thus applying a constant delicate pressure on the canal walls (15). When inserted into a root canal, it adapts itself to the canal's shape, both longitudinally (as will any nickel titanium file) and along the cross-section. In a round canal, it will attain a round cross-section, whereas in an oval or flat canal it will attain a flat or oval cross-section, providing a three-dimensional adaptation (Fig. 5*C*). The surface of the lattice threads is lightly abrasive (Fig. 5*D*), which allows it to remove dentin with a back-and-forth grinding motion (15).

The SAF is operated with transline (in and out) vibrating handpieces with 3,000 to 5,000 vibrations per minute and an amplitude of 0.4 mm. Such a handpiece may be the KaVo GENTLEpower or equivalent combined with either a 3LDSY head (360° free rotation; Kavo, Biberach Riss Germany) (Fig. 6) or MK-Dent head (360° free rotation; MK-Dent, Bargteheide, Germany) or RDT3 head (80 rpm when free and stops rotating when engaging the canal walls, recently developed by Re-Dent-Nova, Ra'anana, Israel). The vibrating movement combined with intimate contact along the entire circumference and length of the canal removes a layer of dentin with a grinding motion (see later).

The hollow design allows for continuous irrigation throughout the procedure. A special irrigation device (VATEA, ReDent-Nova) is connected by a silicon tube to the irrigation hub on the file (Fig. 5*A* and 6) and provides continuous flow of the irrigant of choice at a low

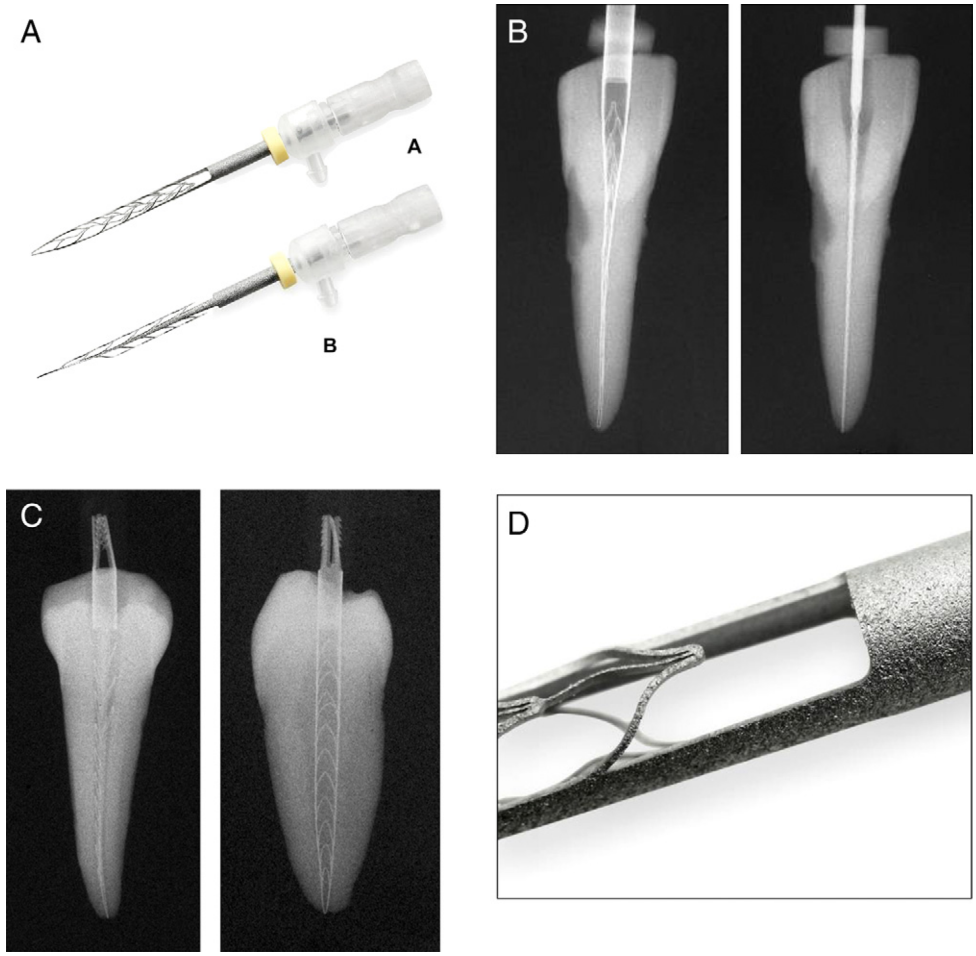


**Figure 5.** (*A*) The SAF. (*A*) Shank for attachment to a transline vibrating handpiece (in-and-out motion). (*B*) Connector (hub) for the irrigation tube. (*B*) The SAF compressed into a canal prepared by a # 20 K file. Right: A # 20 K file. (*Left*) The SAF compressed into the same canal. (*C*) Three dimensional adaptation of the SAF file. The SAF inserted into the root canal of a lower bicuspid with a flat canal. Left: bucco-lingual projection. (*Right*) Mesiodistal projection. (*D*) Abrasive surface of the SAF file (25× magnification).

pressure and at flow rates of 1 to 10 mL/min. Alternatively, any physiodispenser type of irrigation device (ie, NSK Surgic XT Micro Motor System, Kanuma, Japan, or W&H ImplantMed, Burmoos, Austria) that is primarily designed for implantology may also be used.

The SAF is inserted into the canal while vibrating and is delicately pushed in until it reaches the predetermined working length. It is then operated with in-and-out manual motion and with continuous irrigation using two cycles of 2 minutes each for a total of 4 minutes per canal. This procedure will remove a uniform dentin layer 60- to 75-$\mu$m thick from the canal circumference (15) (Fig. 7*A* and *B*). The SAF file is designed for single use.

## An Self-adjusting File that Adapts Itself to the Three-Dimensional Anatomy of Root Canals

The SAF file is different from any current nickel-titanium rotary file. Most rotary file systems will find the widest part of the canal and gradually machine it, using several files of increasing diameter, to a wider canal with a round cross section. If the canal happens to be relatively narrow, the whole original canal may be included in the preparation. However, if the canal is flat, oval, tear shaped, or simply large, this mode of preparation may leave untreated recesses, mainly buccally or lingually to the machined part of the canal (Figs. 2 and 3*A* and *B*).

The SAF is used as a single file (of either 1.5- or 2.0-mm diameter) that starts as a narrow, compressed, shape and gradually expands in the canal while removing a uniform layer of dentin from its walls. Because the file adapts itself to the cross-section of a given canal, a canal with a round cross-section is enlarged as a round canal, whereas an oval canal is enlarged as an oval canal of larger dimensions (Figs. 2 and 7*A*). Even an extreme root canal anatomy, such as presented in Figure 7*B*, lends itself to this mode of operation. High-resolution three-dimensional micro-CT analysis showed that high percentage (83.2%) of the canal wall is affected by the SAF file even in oval, flat root canals (Table 1).

## Uniform Removal of Dentin and Remaining Wall Thickness

When operated in flat root canals, rotary nickel-titanium files may result in uneven thickness of the remaining dentin wall. In places in which the round bore has been created, the remaining dentin will be thinner in the mesial and distal aspects than in the untreated areas (Fig. 2). When excessive apical preparations are used in an attempt to include as much of the irregular canal space in the preparation as possible (16, 17), the uneven thickness may be even more pronounced. This uneven thickness of the remaining dentin wall may be

**Figure 6.** A KaVo transline vibrating handpiece. The irrigation tube is connected to a continuous-flow source and has an on-off switch (white).

a predisposing factor for vertical root fractures (14). On the other hand, the SAF removes a uniform layer of dentin from the canal walls, thus resulting in a relatively uniform remaining dentin wall thickness and avoiding the previously mentioned risk (Figs. 2 and 7*A* and *B*).

## Prevention of Canal Transportation

The SAF file is extremely flexible and pliable. It does not impose its shape on the canal but rather complies with its original shape. This is true both circumferentially and longitudinally. The long axis of the apical part of curved canals is kept closer to its original place than reported for rotary files: a mean center-of-mass shift of 68.8 $\pm$ 7.7 $\mu$m compared with the shift of 120 to 135 $\mu$m previously reported by Peters et al with rotary files in similar canals (10) (Table 2 and Fig. 8*A*). In curved canals, the thicker rotary nickel-titanium files have a tendency to transport the canal to the outer side of the curvature (Fig. 4) (10). When the SAF is used to enlarge the canal to similar dimensions, it tends to keep the apical part of curved canals closer to its original location (Fig. 8*A*).

When rotary files accidentally pass the apical foramen of an apically curved canal, because of misleading length measurement or failure to maintain the marker in place, they may soon "zip" the apical foramen and form an oval opening. The SAF, on the other hand, may be operated in such conditions even for few minutes with no zipping whatsoever (Fig. 8*B*).

## High Durability

The SAF file is extremely durable and may go through rather severe abuse before a mechanical failure will occur. It does not have a core as do other nickel-titanium instruments. Any strain applied to it is distributed along many of its delicate parts, and the total endurance is a function of the accumulated endurance of each of these individual parts.

Some of the tests used to compare the endurance of endodontic files are not directly relevant to this file's mode of operation; nevertheless, they are indicative of its high durability (15). When torque durability was tested, the SAF can be turned 7 $\times$ 360° before separation with a torque durability of 29.7 g/cm (15). These values are well beyond the ISO3630-1 requirement (1 $\times$ 360° rotation and 18 g/cm in the torque durability test) and above that of many of the instruments compared in a recent American Dental Association Professional Product Review (18).

When the American Dental Association cyclic fatigue test is applied, SAF can be rotated for more than 150 hours at 900 rpm with a 5-mm deflection with no mechanical failure (15), whereas some of the nickel-titanium rotary instruments separated within the first hour or even within a few minutes (18). As mentioned previously, these tests are indicative of the SAF's durability, even though the SAF's mode of operation is a transline vibrating motion. A buckling test is more relevant to study the endurance of the SAF. The SAF can endure more than 600,500 consecutive 6-mm type I free buckling cycles before any mechanical damage could be observed (15). This represents an equivalent of $\sim$120 minutes of a rather abusive operation at 5,000 vibrations per minute.

A specially designed test apparatus (Fig. 9*A*) allows the SAF to be continuously operated in simulated canals using the up and down motion of the handpiece, as used clinically. During this testing, the instruments were taken out and inspected every 1 minute. The SAF file was operated in this test for 29.1 $\pm$ 1.2 minute before any structural failure appeared (15) (Fig. 9*A*).

After all this, the ultimate endurance test is the real-life test: operation in root canals. The SAF can be operated for 27 minutes in extracted human teeth before any structural failure appears. This represents more than 6 times the 4-minute operation time per canal, which is sufficient to achieve the desired results (15).

It is of particular importance to note that even when structural failure did occur, it was not of the separation type that is encountered with other nickel-titanium files. Detachment of one of the arches at one of its ends was the typical mechanical failure (15) (Fig. 9*B*). The damaged file could easily be retrieved from the canal, facing none of the challenges that a separated rotary nickel-titanium file presents.

## Continuous Irrigation with Sodium Hypochlorite

Irrigation of the root canal with copious amounts of sodium hypochlorite during root canal treatment is widely recommended (19, 20). It has been well documented that when exposed to its target of bacteria and tissue debris, sodium hypochlorite loses its activity rather quickly (21). Taking into account the extremely small volume of the root canal, the amount of sodium hypochlorite contained in the canal loses its activity within a very short time. Therefore, as frequent replacement of the irrigant as possible is mandatory for maintaining its optimal potency and effect.

The SAF operates with a continuous flow of the irrigant, thus allowing continuous fresh irrigant to be present in the canal at all times. The vibration of the file's metal lattice within the irrigant facilitates its cleaning and debridement effects (22, 23).

Effective sodium hypochlorite replacement in the apical part of the canal is essential to provide its full effect and benefits in this critical area during root canal treatment. The extent of irrigant replacement in the apical part of curved narrow canals was previously studied using clear resin blocks with simulated curved canals filled with colored liquid

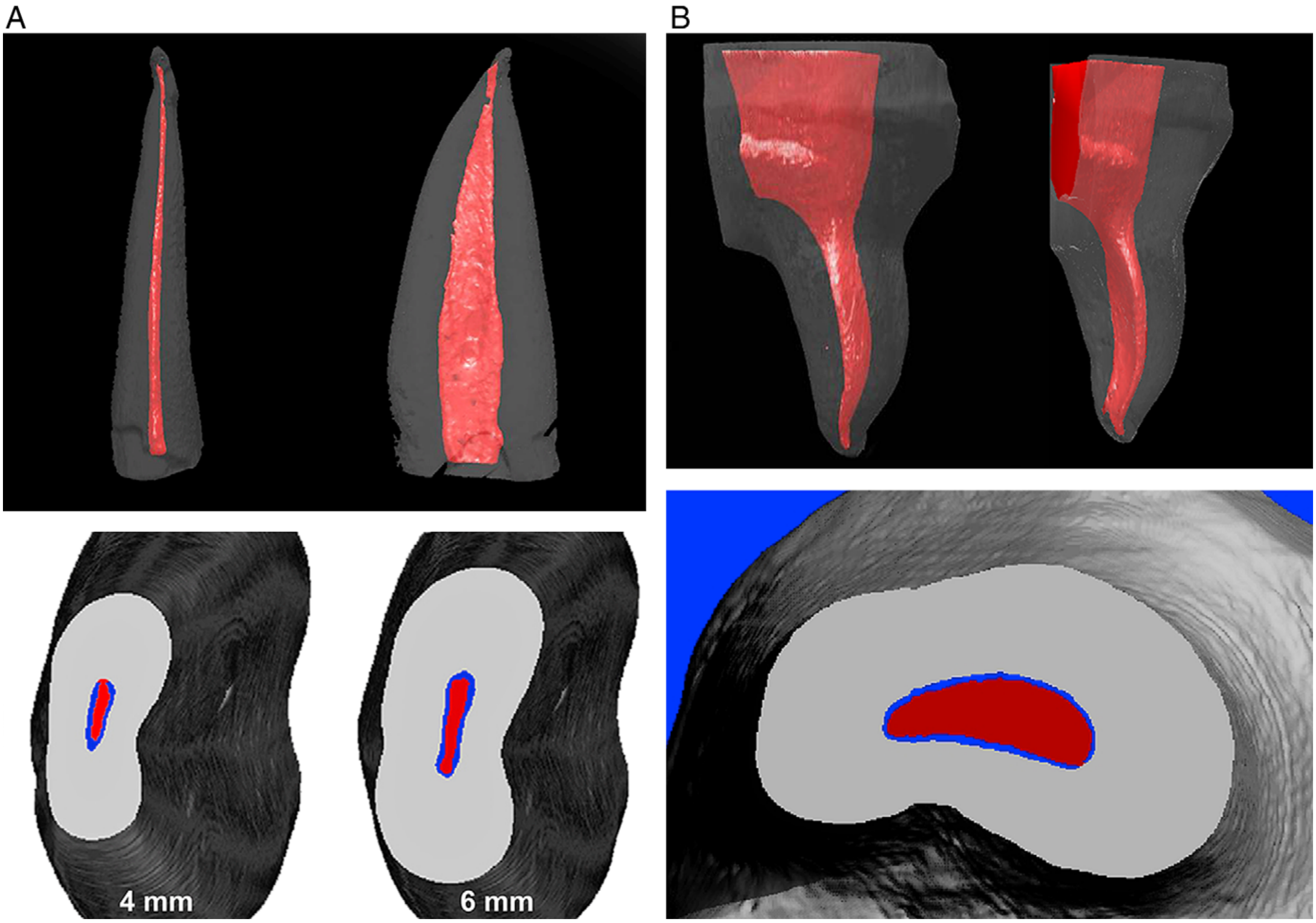


**Figure 7.** (*A*) SAF preparation: an upper second bicuspid with a flat root canal. (*Top*) Buccal and mesial views. (*Bottom*) Cross-sections at 4 and 6 mm from the apex. A micro-CT analysis. Red, before; blue, after. (*B*) SAF preparation: distal root of a first lower molar. (*Top*) Two views presenting a curved flat canal with a mesial, spoon-shaped concavity. (*Bottom*) Cross-section at 6 mm from the apex. A micro-CT analysis. Red, before; blue, after.

(24). Using the same model, it was evident that syringe and needle irrigation was ineffective in replacing the liquid in the apical part of a narrow curved canal. On the other hand, the SAF, which was used with continuous irrigation, combined with the vibrating action of the metal lattice, was effective at replacing the liquids in the apical part of the canal (Fig. 10*A*).

The effective replacement of irrigant in the apical part of the canal occurs with no clinically significant positive pressure. No pressure builds up in the canal during the SAF operation because the metal mesh allows free escape of the irrigant at all times. Even in the narrow apical part of a canal 200 $\mu$m in diameter (a canal prepared up to a #20 K-file), the SAF represents a very ineffective piston, with 38% of the canal cross-section area free for the irrigants backflow (Fig. 10*B*) (15).

No irrigant passes the apical foramen during SAF operation (15). This may be understood if pressure analysis in this critical area is studied. Three pressure types may potentially be present in the apical part of the canal during SAF operation: hydrostatic pressure representing the water column in the canal, stagnating pressure generated by the vibration of an object in the fluid, and piston pressure resulting from the apical thrust of the SAF. All these may be calculated and sum up to a total pressure of 394 Pa (15).

The simple surface tension of the external fluid at an even larger apical foramen 350 $\mu$m in diameter requires a calculated eruption pressure of 832 Pa to allow fluid from the canal to escape beyond the apical foramen (15). The pressure required will be much higher if tissue is present periapically. Therefore, the passage of irrigant to the periapical area as a result of the SAF's action is highly unlikely. This is in agreement with the lack of any postoperative pain when the SAF is used clinically.

These values should be compared with (i) the potential calculated piston pressure that a well-adapted K-file might generate when introduced into the apical part of a narrow canal full of irrigant ($\sim$199,700 Pa when a #25 file is pushed with a force of 1 g) (15) and (ii) with the pressure generated when a syringe is used for irrigation at 5 mL/min with a 25-G needle that is loosely adapted into the canal space. Even if 38% of the cross-section area of the canal is left free around the needle, for the escape of the irrigant's backflow, a calculated pressure of 1,270 Pa will occur (15).

## Removal of the Smear Layer in the Apical Part of the Canal

As with any other mechanical device, the SAF forms a smear layer on the canal walls (23). This layer should be removed in order to allow intimate, unobstructed contact of antibacterial agents with bacteria at the orifices of dentinal tubules and also to optimize the sealer's adaptation to the canal walls and thus prevent the future formation of a gap between them (25–27). A final wash with a chelating agent

**TABLE 1.** Micro-CT Analysis of SAF Preparation in Oval and Flat Root Canals

| | Tooth type | B-L: M-D ratio* | Percent unchanged† (±SEM) |
|---|---|---|---|
| 1 | Mandibular premolar | 1:3 | 15.9 |
| 2 | Maxillary premolar | 1:2 | 5.8 |
| 3 | Mandibular incisor | 1:3 | 29.6 |
| 4 | Maxillary premolar | 1:4 | 20.0 |
| 5 | Mandibular incisor | 1:2 | 20.2 |
| 6 | Maxillary premolar | 1:4 | 13 |
| 7 | Mandibular incisor | 1:3 | 21.1 |
| 8 | Maxillary lat. incisor | 1:2 | 5.2 |
| 9 | Mandibular incisor | 1:2 | 7.1 |
| 10 | Maxillary lat. incisor | 1:3 | 30.5 |
| Mean | | | 16.8 (±2.9) |

SAF, self-adjusting file; SEM, standard error of the mean.

*Ratio between buccolingual and mesiodistal dimensions of the root canal, at 4 mm from the apex, used as a measure of the canal's flatness.

†Percent of root canal walls pixels before the procedure unaffected by the file, calculated from before and after micro-CT scans, as done by Peters et al (10).

**TABLE 2.** Canal Transportation by the SAF File in the Apical Third of Curved Root Canals: Center-of-Mass Shift Analysis*

| Root type | Center of mass shift in the apical third |
|---|---|
| MB root of maxillary molar | 104.7* |
| DB root of maxillary molar | 92.6 |
| Palatal root of maxillary molar | 41.3 |
| Palatal toot of maxillary molar | 58.5 |
| DB root of maxillary molar | 35.8 |
| Palatal root of maxillary molar | 86.3 |
| MB root of maxillary molar | 58.3 |
| Palatal root of maxillary molar | 74.9 |
| MB root of maxillary molar | 35.38 |
| Palatal root of maxillary molar | 68.8 |
| Mean (± SEM) | 68.8 (± 7.65) |

DB, distobuccal; MB, mesiobuccal; SAF, self-adjusting file; SEM, standard error of the mean.

*Mean center of mass shift ($\mu$m) calculated from before and after micro-CT scans (10).

such as EDTA or citric acid has recently become widely used to remove the smear layer before obturation. Nevertheless, scanning electron microscopic studies indicate that the removal of the smear layer and ultramicroscopic debris in the apical third of the canal using either a syringe and a needle or a chelator paste leaves much to be desired (28–31).

When 3% sodium hypochlorite and 17% EDTA were used as alternating irrigants with the SAF file, the root canal surface (including its apical third) was rendered clean of debris and the smear layer (23) (Fig. 11). This may be attributed to both the effective continuous replacement of the chelator in the apical region and to the mechanical

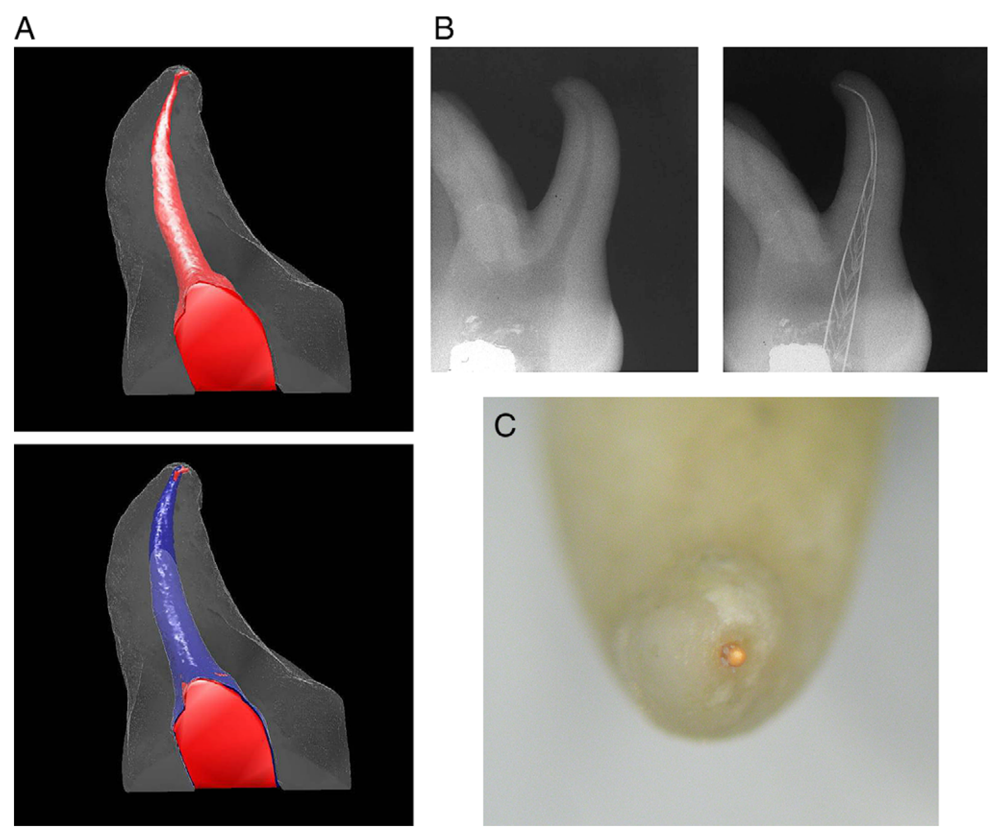


**Figure 8.** (*A*) SAF preparation in a curved canal. A micro-CT scan and analysis. (*Top*) Before treatment (red) and (*bottom*) after treatment (blue). (*B*) Preservation of the apical foramen. (*A*) A sharp apical curve with the foramen facing laterally. (*B*) A SAF file was passed through the apical foramen and operated for 4 minutes. (*C*) The apical foramen was kept round and was not zipped by the procedure.

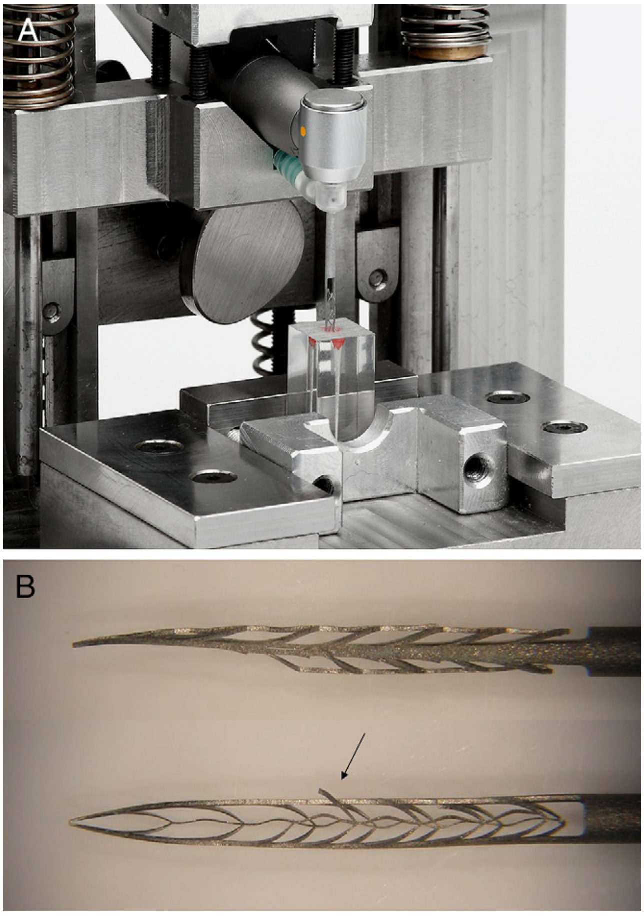


**Figure 9.** (*A*) A testing setup for SAF file durability. The file is operated using a vibrating handpiece which is moved slowly up and down, mimicking the clinical operation. (*B*) Mechanical failure of the SAF. One connector detached at one of its ends. The instrument was easily retrieved from the canal.

vibrating action of the SAF in this region. This combination results in a cleaner apical canal surface than most other reported methods can achieve (23, 28–31).

## Root Canal Obturation

Root canal obturation of SAF-prepared root canals may be done by any of the common methods. Adaptation to the canal walls is possible even in flat canals because of the thorough cleaning of the otherwise difficult to clean recesses (Fig. 12*A*).

Obturation using lateral compaction using chloroform-dipped customized master cones (3, 32) is of particular interest because it allows the operator to actually visualize the shape of the SAF-treated root canal as reproduced on the customized master cone. Such master cones are presented in Figure 12*B*. It is evident that the apical part of the preparation is far from being round in the cross-section but rather represents the enlarged 3D shape of the canal. It is also clear that if a standardized master cone is used to gauge the prepared canal size, it may provide rather limited and misleading information (Fig. 12*B*).

## Clinical Use

The SAF file has been approved for clinical use in Israel (Israeli Ministry of Health, License no. 11940000) as well as in Europe (CE mark no. 0483). A series of clinical vital and nonvital cases have already

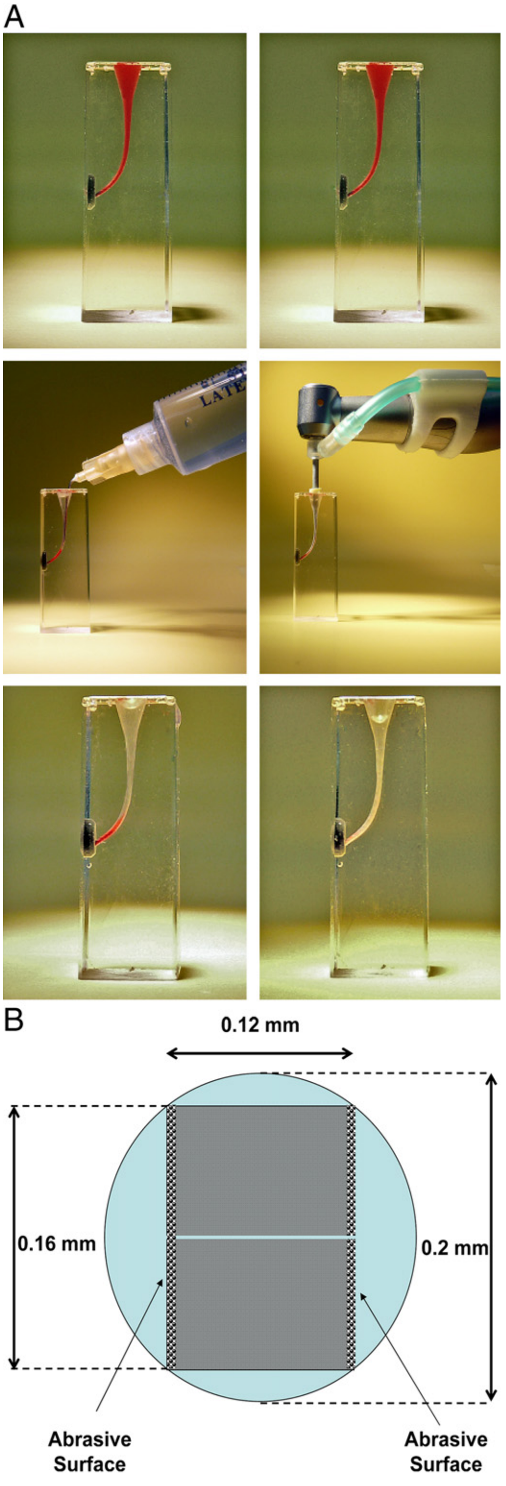


**Figure 10.** (*A*) Replacement of irrigant in the apical third of a curved canal. Curved canals in clear training blocks were filled with colored liquid. (*A*) Needle irrigation failed to wash out the colored liquid. (*B*) The SAF operated with continuous irrigation and vibration washed the colored liquid out. (*B*) A schematic presentation of the apical part of the SAF in a narrow root canal that was prepared to #20 K-file. The apical part of the SAF collapses to a dual layer of metal, each element of which is 0.12-mm thick and 0.8-mm wide, thus forming a potential piston with a 0.12 × 0.16 mm rectangular cross-section. When moving into the canal, 40% of the cross-section of the canal is free and allows backflow of the irrigant, thus being a poor piston that cannot significantly raise the pressure.

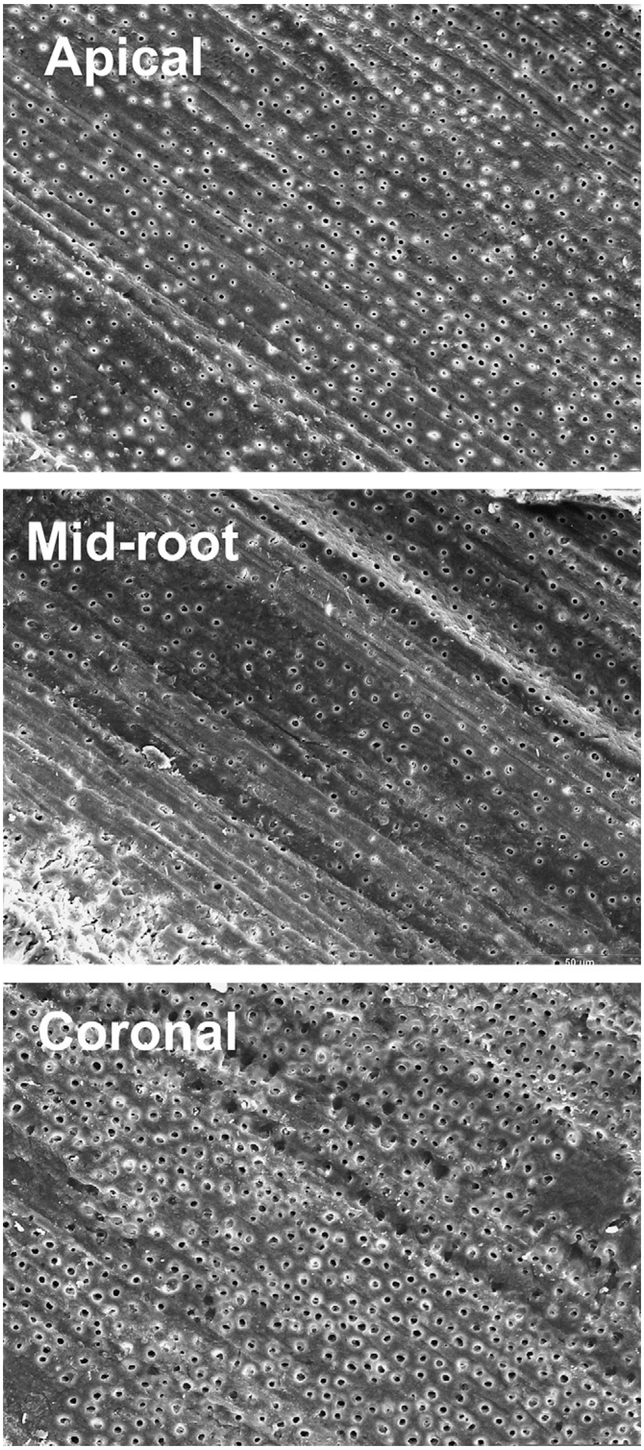


**Figure 11.** Removal of the smear layer. The SAF was operated for two cycles of 2 minutes with a continuous flow of 5% sodium hypochlorite during the first minute of each cycle and 17% EDTA during the second minute. This was followed by a 0.5-minute EDTA flush through a passive SAF and a final short flush with sodium hypochlorite to remove the EDTA. Representative fields from the apical, midroot, and coronal thirds of the root canal. Scanning electron microscopic magnification: ×1,000.

been completed (Fig. 13). The radiographic images of root canal fillings in SAF-prepared canals are no different than those of root canal fillings in root canals prepared by other file systems (Fig. 13). No file separation event was recorded in more than 100 clinical cases.

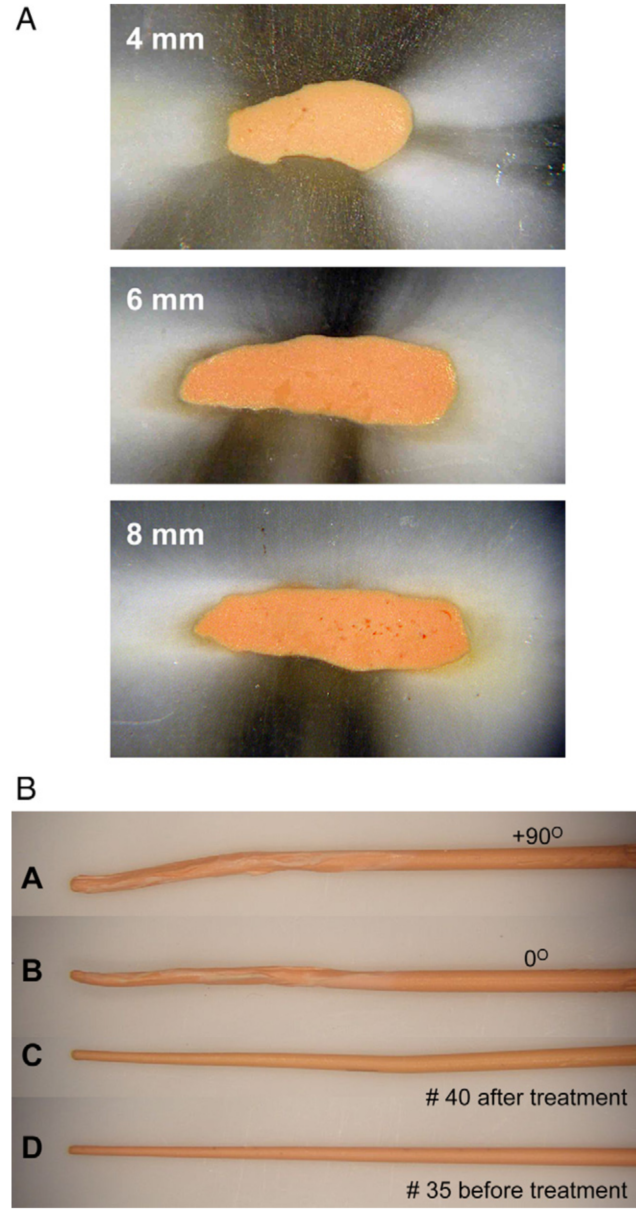


**Figure 12.** (*A*) Root canal filling adaptation in a SAF-prepared flat root canal. The entire circumference of the canal was prepared, thus allowing root canal filling penetration into the buccal and lingual areas of the canal. Cross-sections at 2, 4, and 6 mm from the apex. (*B*) Chloroform-dipped customized master cones. They present a three-dimensional reproduction of the SAF-prepared canal (*A*, *B*, rotated by 90°). (*C*) The standardized master cone fit with a tug-back sensation in the same prepared canal. (*D*) A master cone that fit into the canal before SAF preparation.

## Conclusions

The SAF represents a new approach in endodontic file design and operation. Its main features are as follows:

1. A three-dimensional adaptation to the shape of the root canal, including adaptation to its cross-section.
2. One file is used throughout the procedure, during which it changes from an initially compressed form to larger dimensions.

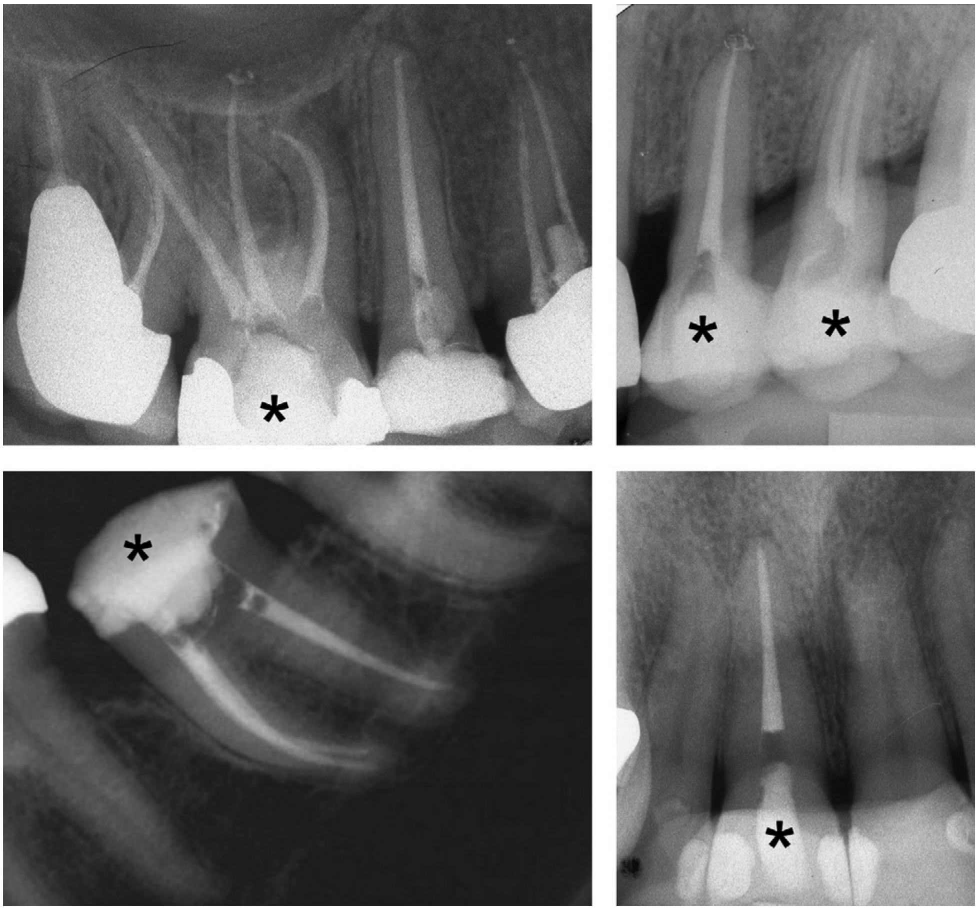

**Figure 13.** SAF in clinical use. Postoperative radiographs of clinical cases treated with the SAF file. *SAF-treated teeth.

3. Canal straightening and canal transportation of curved canals are largely avoided because of the lack of a rigid metal core. The file does not have "a will of its own."
4. High mechanical durability, thus overcoming the issue of separated nickel-titanium instruments.
5. Hollow design that allows continuous irrigation with constant refreshment of the irrigant throughout the procedure.

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