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Pattern of endodontic instrument separation and factors affecting its retrieval: a 10-year retrospective observational study in a postgraduate institute

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ABSTRACT

Objectives: This study aimed to assess the pattern of endodontic instrument separation, their retrievability, and factors affecting its retrieval, in a postgraduate institute.

Methods: Cases referred for the management of separated endodontic instruments (SEI) from 2013 to 2023 were considered for this study. Data related to demographics, tooth type, file type, and retrieval were documented in an Excel sheet. Eight prognostic factors assumed to influence the retrieval were analyzed in this study. The secondary aim was to compare the pattern of SEI and retrievability between conventional nickel-titanium files and newer generation heat-treated nickel-titanium files. Retrieval was attempted by a senior endodontist under the dental operating microscope. Various ultrasonic tips and a Broken Tool Removal loop system were used during retrieval. Simple descriptive statistics were performed. Binomial logistic regression was done to identify the effect of the eight prognostic factors on the retrieval outcome.

Results: A total of 190 SEI was reported. SEI occurred more often in posterior teeth than anterior teeth, mandibular arch than maxillary arch, and in larger files than smaller files. Separation occurred more often in the apical third compared to the other levels. Retrieval was attempted in 88 cases and successful in 70 cases (79.5%). The larger taper and apical position of the SEI negatively influenced the retrieval by 1.4 and 8.7 times, respectively.

Conclusions: Retrieval of SEI was successful in the majority of the cases. An increase in taper and apically placed SEI negatively impacted the retrieval. There was no difference in the pattern of separation nor retrievability between conventional nickel-titanium files and newer generation heat-treated nickel-titanium files.

Keywords: Broken instrument retrieval; Fractured instrument; Instrument removal; Ultrasonics

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INTRODUCTION

Separated endodontic instruments (SEI) during cleaning and shaping, is a challenging clinical situation. Disinfection of the root canal system is affected by the presence of a SEI, which can ultimately compromise the treatment outcome [1]. To date, mechanical enlargement of the root canals is mostly done using nickel-titanium (NiTi) instruments. These instruments have a higher incidence of separation inside the root canal than stainless steel instruments [2]. Previous literature has shown the prevalence of SEI ranging from 0.4% to 5% [3,4].

The recent NiTi files are manufactured using heat-treated alloys, which are claimed to have superior fracture resistance and enhanced flexibility [5]. Apart from these, changes in NiTi file design elements like variable taper, asymmetrical cross-section, and newer motion kinematics like, torque control motors with auto reverse function, reciprocation, and self-adjusting files are other methods that have been introduced to decrease the incidence of file separation [6–10]. The clinical incidence of SEI for rotary motion is 2.43%, while for reciprocation it is 1% [11]. Previous studies have reported, SEI to occur more commonly in the mesial roots of molars and the apical third of the root canal [12,13]. It is still unclear if this pattern of separation is seen with the newer generation NiTi files.

SEI can be retrieved using nonsurgical or surgical techniques. With advances in technology, newer techniques, and microscopic instruments are available for instrument retrieval which can give a predictable outcome [14–18]. Knowing the pattern of separation and the factors affecting the retrieval of separated instruments in such scenarios will be interesting.

Hence, the aim of this retrospective observational study was, to assess the pattern of instrument separation (level and length), the type of tooth/root canal, the technique used for retrieval, retrieval success, and factors that influence retrieval of SEI. The secondary aim was to assess any difference between newer generation heat-treated NiTi files and conventional NiTi files in terms of SEI pattern and retrieval.

METHODS

This observational study has been reported according to the STROBE (STrengthening the Reporting of OBservational studies in Epidemiology) guidelines [19] (Figure 1). This study was conducted in the Department of Conservative Dentistry and Endodontics. Ethical approval for this study was granted by the Institutional Ethical Committee (No. MADC/IEC/III/89/2023) of the dental college. The study population comprised patients who had been treated for SEI between 2013 and 2023 in the postgraduate department. The record of 190 patients who had a SEI during their root canal procedure or were referred to the department for management of SEI was considered for this study. The data was collected using

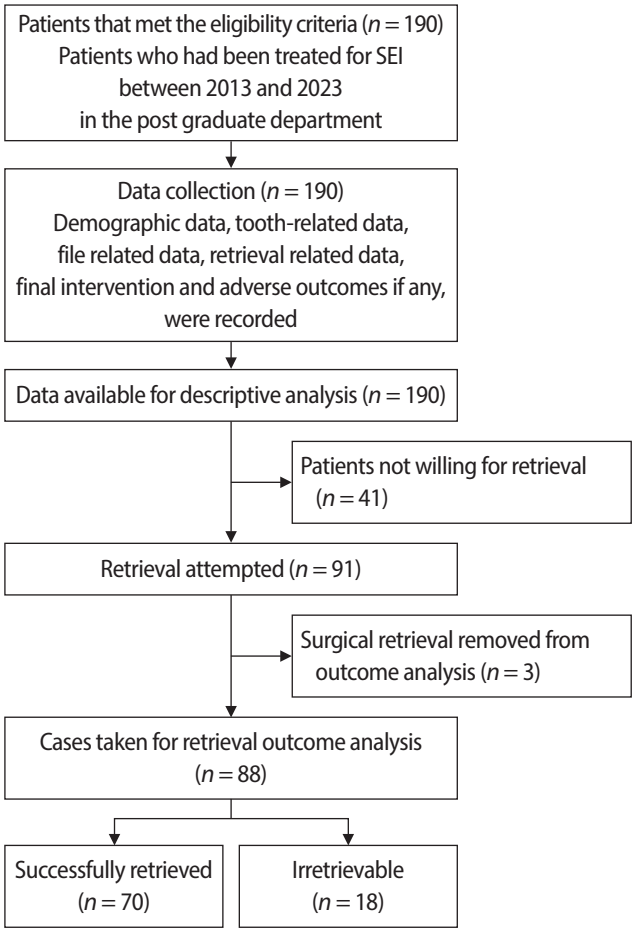

Figure 1. STROBE (STrengthening the Reporting of OBservational studies in Epidemiology) flowchart. SEI, separated endodontic instrument.

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a pre-piloted data sheet using Microsoft Excel. It was divided into, demographic data (age and sex), tooth-related data (diagnosis of the tooth, primary/secondary treatment tooth, arch, curvature, presence of calcification, canal, level of fracture, curvature), file-related data (type of file, kinematics, material, file size, length of file, taper). Additionally, if the retrieval was attempted, the technique used for retrieval, success or failure of retrieval, final intervention (extracted, bypassed and obturated, obturated till the level of separation), and adverse outcomes if any were recorded.

Treatment protocol

All the patients were first informed about the presence of a SEI. The various treatment options were explained to the patients by a staff member and final treatment was commenced after obtaining the patient's consent. All the treatments were carried out by a senior endodontist, with more than 15 years of experience (VN) using a dental operating microscope (Labomed Dental Microscope Prima DNT, Fremont, CA, USA) under rubber dam isolation.

Retrieval procedure

In a tooth with multiple canals, the root canals other than the one with SEI were blocked out using gutta-percha/temporary stopping/polytetrafluoroethylene tape, before attempting to remove the separated instrument. The SEI was removed using different techniques such as direct/indirect ultrasonic vibrations alone or in combination with a loop device, Broken Tool Removal (BTR) pen (Cerkamed Medical Company, Stalowa Wola, Poland). For the staging platform (Ruddle's technique), the root canal was enlarged using Gates Glidden drill size 2 or 3. Once the coronal portion of the root canal was enlarged up to the separated instrument, various ultrasonic tips were used for retrieval. These included ET20 and ET40 (Endo Success Tips; Acteon, Mérignac, France), the Ultra X Tip (distributed by Orikam Healthcare; Eighteeth Medical, Mumbai, India), ultrasonic tips 87, 88, and 89 from the Terauchi File Retrieval Kit (Dental Engineering Laboratories, Santa Barbara, CA, USA), and U Files in sizes 15 and 20 (Mani Inc., Utsunomiya, Japan). A combination of various tips was also used when required. The retrieval was attempted using ultrasonic tips under a low-power setting. If the separated instrument was not retrieved by direct ultrasonic vibrations, the instrument was further loosened using U tips size 20 (U Files), following which, it was removed using the BTR loop device. If retrieval was unsuccessful, the instrument was either bypassed or canals were obturated till the level of instrument separation. The instrument removal system and canal braiding using H files were used to remove the separated files in two and one cases, respectively. In three cases, the surgical retrieval was done under local anesthesia by a specialist. As the number of cases taken for surgery was less, they were not considered for retrieval statistical analysis.

Statistical analysis

Simple descriptive statistics (frequencies and proportions) were used to represent the distribution of the data. A binomial logistic regression was performed to identify the effect of eight prognostic factors such as the position of the tooth (anterior or posterior), arch (maxillary or mandibular), curvature (mild or moderate), file size, the taper of the instrument, level of the separated instrument (coronal two-third, apical third), length of the file (<5 mm, 5–10 mm, or >10 mm) and file type (conventional file or heat-treated file) on the odds of failure to retrieve the instrument among the cases in which instrument retrieval was attempted. File size and taper of the instrument were considered continuous variables. The reference categories used in the six categorical predictor variables, namely the position of the tooth, arch, curvature, level of the separated instrument, length of a file, and file type, were anterior, maxillary, mild, coronal two-thirds, <5 mm, and conventional files, respectively. To ensure the reliability of our findings and address challenges posed by limited sample size and sampling variability, bootstrapping was employed in our logistic regression analysis. This resampling technique involves drawing repeated samples from the dataset with replacement to estimate the sampling distribution of regression coefficients. By conducting 1,000 bootstrap resamples, we derived 95% confidence intervals (CIs) for coefficient estimates and their standard errors, thereby enhancing the robustness of our results. The statistical analysis was performed using IBM SPSS for Windows, version 27 (IBM Corp., Armonk, NY, USA).

RESULTS

A total of 190 cases of SEI were reported during the study period. The age of the study population was 39.08 ± 12.9 years. In eight cases, the nature of the file type was unknown as these were referred from outside the department for retrieval and so their data was used only to determine the pattern of separation and not for determining the generation of NiTi instruments. Among the NiTi files, 55.3% were conventional NiTi and 40.5% were heat-treated NiTi files. SEI occurred more commonly in posterior teeth (86.8%) than anterior teeth (13.2%) and more often in mandibular teeth (59.5%) than in maxillary teeth (40.5%).

With regard to the sizes of the SEI, 11.5% were below size 15, 56.5% were between 15 and 25, 29.2% were between 25 and 40, and 2.8% were above size 40. With regards to taper, the SEI prevalence of 2%, 4%, 6%, and >6% tapered instruments were 31.5%, 27.9%, 23.8%, and 16.6%, respectively. The length of the SEI was <5 mm in 77.9%, 6–10 mm in 16.8%, and >10 mm in 5.3%.

The maximum number of SEI occurred in the apical third region (46.8%) and the least in the coronal third region (6.3%). The prevalence in the middle third was 16.3%. Apart from this SEI were located, in the cervico-middle and apical-middle levels in 2.6% and 15.3% of the cases, respectively. In 4.7% of the cases, SEI occurred along the full length of the root canal and in another 7.9% of the cases, the files were separated beyond the apex. In 84.2% of the cases, the instrument separation occurred in teeth with moderate to severe curvature and 15.8% in cases with mild curvature. The pattern of instrument separation was similar with both conventional NiTi files and newer generation heat-treated NiTi files.

A total of 88 patients opted for removal of SEI and complete retrieval was possible in 70 of these cases (79.5%). A few of the successful cases have been rep-

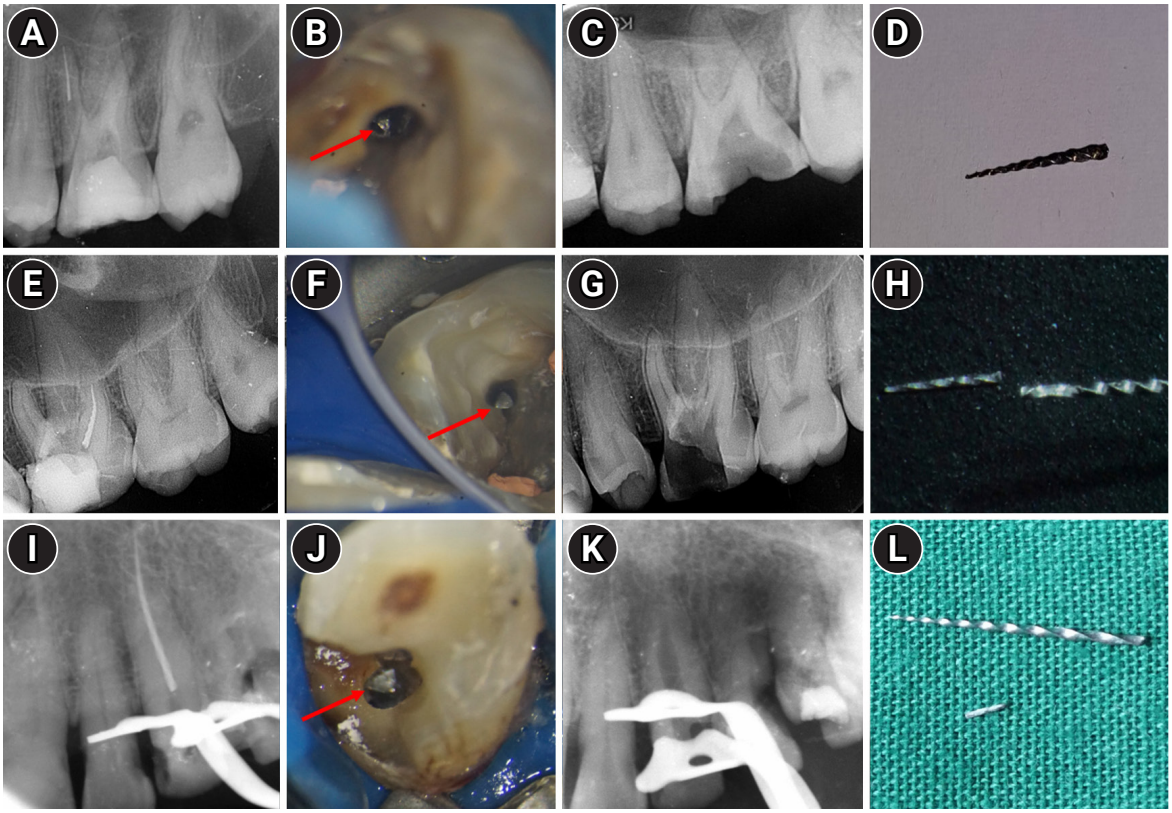

Figure 2. Retrieval of separated endodontic instruments (A–D, Case I; E–H, Case II; I–L, Case III). (A) Separated instrument in the apical third. (E) Full-length separation of the instrument. (I) Full-length separation of instrument. (B, F, J) Separated instrument viewed under a dental operating microscope (arrows). (C, G, K) After retrieval. (D, H) Retrieved instrument. (L) Retrieved instrument with fractured ultrasonic tip.

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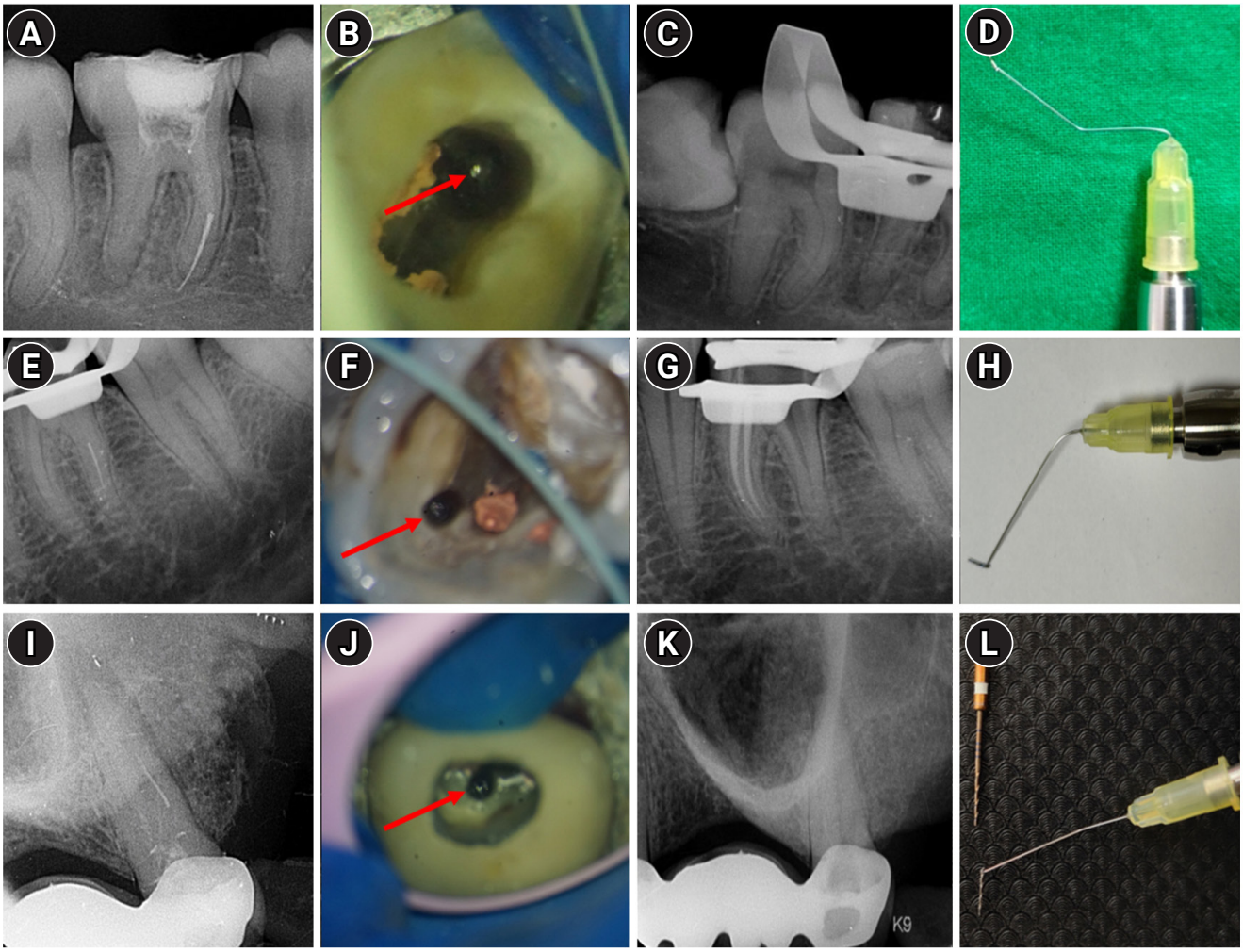

Figure 3. Retrieval of separated endodontic instruments using a broken tool removal (BTR) pen (A–D, Case I; E–H, Case II; I–L, Case III). (A) Separated instrument beyond the apex. (E) Separated instrument in middle third. (I) Separated instrument in the middle third of the crowned tooth. (B, F, J) Separated instrument viewed under a dental operating microscope (arrows). (C, G, K) After retrieval. (D, H, L) Retrieved using BTR pen.

resented in Figures 2 and 3. In the remaining 18 cases (20.5%), retrieval was unsuccessful. Of those 18 cases, in 11 cases the SEI was bypassed and obturated and in seven cases the teeth were obturated at the level of SEI (Table 1). Of the 102 patients who did not want retrieval, 41 of them did not report back for any further treatment, and in all the remaining cases, the root canals were either bypassed or obturated till the level permissible.

Ultrasonics was the most commonly used method for the retrieval of SEI in 73.9% of the cases (Figure 2). In 22.8% of the cases, ultrasonics and BTR were used (Figure 3). The iatrogenic events that occurred during retrieval were perforations (<1%), secondary fracture of SEI (11.4%), fracture of ultrasonic tips (17.0%), and ledge formation (<1%) (Figure 4). There was no difference in retrievability between conventional NiTi files and newer generation heat-treated NiTi files.

Various independent factors such as the position of the tooth, arch, file size, curvature, length of file, and file type did not affect the outcome of retrieval (Table 2). The odds ratio (OR) of failure and its 95% CI values for all the prognostic variables are presented in Table 3. Of the eight prognostic factors included in the model, only two (taper and level of the separated instrument) were found to be statistically significant ($p < 0.05$) and to have influenced the retrieval. An increase in the taper by ev-

Table 1. Descriptive statistics: distribution of the separated endodontic instruments across various independent factors (n = 190)

Variable	Data
Sex	
Female	98 (51.6)
Male	92 (48.4)
Position of the tooth	
Anterior	25 (13.2)
Posterior	165 (86.8)
Arch	
Maxillary	77 (40.5)
Mandibular	113 (59.5)
Curvature	
Mild	30 (15.8)
Moderate	160 (84.2)
File type	
Conventional NiTi	105 (55.3)
Common heat-treated NiTi	77 (40.5)
Unknown	8 (4.2)
Level	
Coronal	12 (6.3)
Middle third	31 (16.3)
Apical	89 (46.8)
Full length	9 (4.7)
Apical and beyond	15 (7.9)
Apico-middle	29 (15.3)
Cervico-middle	5 (2.6)
Level of the separated instrument	
Coronal two-third	57 (30.0)
Apical third and beyond	133 (70.0)
Length of file (mm)	
<5	148 (77.9)
6–10	32 (16.8)
>10	10 (5.3)
Instrument retrieval attempted	
No	102 (53.7)
Yes	88 (46.3)
Final intervention[a]	
Retrieved and obturated	70 (47.0)
Bypass and obturated	63 (42.3)
Extracted	4 (2.7)
Obturated till level of separation	12 (8.1)
Outcome of retrieval[b]	
Unsuccessful	18 (20.5)
Successful	70 (79.5)

Values are presented as number (%).
NiTi, nickel titanium.
[a]n = 149, [b]n = 88.

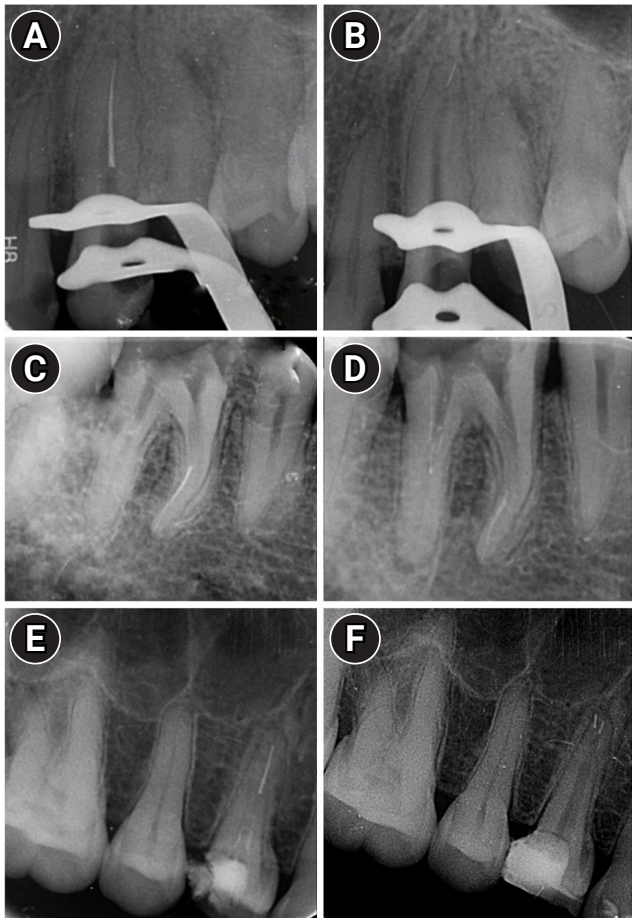

Figure 4. (A) Separated instrument in apical two-thirds. (B) Secondary fracture of the separated instrument. (C) Separated instrument in the apical third. (D) Separated instrument with lateral strip perforation, (E) Separated instrument in the apical third. (F) Secondary fracture of the separated instrument and lateral perforation.

ery unit was associated with increased odds of failure by 1.494 times (OR, 1.494; p = 0.022). In addition, the apical position of the instrument was associated with increased odds of failure by 8.761 times (OR, 8.761; p = 0.013) compared to the coronal two-thirds level. Additionally, our bootstrapped analysis provided further insights into the reliability of our regression coefficients as the estimated 95% CIs for the two predictors (taper and level of the separated instrument) remained significant (Table 4).

DISCUSSION

This study was a 10-year retrospective observational

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Table 2. Outcome of retrieval (count and percentage) based on various independent factors ($n = 88$)

Variable	Unsuccessful ($n = 18$)	Successful ($n = 70$)
Sex		
Female	12 (24.5)	37 (75.5)
Male	6 (15.4)	33 (84.6)
Position of the tooth		
Anterior	3 (16.7)	15 (21.4)
Posterior	15 (83.3)	55 (78.6)
Arch		
Maxillary	7 (38.9)	31 (44.3)
Mandibular	11 (61.1)	39 (55.7)
Curvature		
Mild	5 (27.8)	21 (30.0)
Moderate	13 (72.2)	49 (70.0)
File type[a]		
Conventional NiTi	10 (58.8)	32 (49.2)
Common heat-treated NiTi	7 (41.2)	33 (50.8)
Level		
Coronal	2 (11.1)	5 (7.1)
Middle third	1 (5.6)	15 (21.4)
Apical	4 (22.2)	23 (32.9)
Full length	1 (5.6)	8 (11.4)
Apical and beyond	1 (5.6)	4 (5.7)
Apico-middle	9 (50.0)	10 (14.3)
Cervico-middle	0 (0)	5 (7.1)
Level of the separated instrument		
Easy	3 (16.7)	34 (48.6)
Difficult	15 (83.3)	36 (51.4)
Length of file (mm)		
<5	10 (55.6)	44 (62.9)
6–10	6 (33.3)	18 (25.7)
>10	2 (11.1)	8 (11.4)
Technique[b]		
Ultrasonic	17 (94.4)	48 (71.6)
Ultrasonic BTR	1 (5.6)	19 (28.4)
Final intervention		
Retrieved and obturated	0 (0)	70 (100)
Bypass and obturated	11 (61.1)	0 (0)
Extracted	0 (0)	0 (0)
Obturated till level of separation	7 (38.9)	0 (0)

Values are presented as number (%).
BTR, broken tool removal; NiTi, nickel-titanium.
[a]Unsuccessful $n = 17$; Successful $n = 65$.
[b]Unsuccessful $n = 18$; Successful $n = 67$.

study done to determine the pattern of separated instruments and their management in a postgraduate institute in Chennai, India. The postgraduates were asked to complete root canal instrumentation in 10 extracted teeth before starting a clinical case. The students were instructed to pre-enlarge the root canal using stainless steel hand instruments to size 20 K-file before the use of NiTi instruments. All students performed the instrumentation using endo motors with torque control.

In the event of an instrument separation, the patients were informed about the incident and given the option of retrieval. Retrieval was done by a senior endodontist with more than 15 years of experience, under a dental operating microscope, with rubber dam isolation.

A total of 190 SEI was reported during the 10 years from 2013 to 2023. Nonsurgical instrument retrieval was attempted in 88 cases and the SEI was retrieved successfully in 70 cases (79.5%). A total of 21.6% of the patients did not report back for any further treatment once they were informed about the presence of SEI inside the root canal. The patients would have been apprehensive about the chances of failure and this could have resulted in them not reporting for any further management. A detailed explanation by the concerned clinician is necessary to educate the patients regarding the management of such iatrogenic errors, which could reduce the fallout.

SEI occurred most often in posterior teeth when compared to anterior teeth. The frequency of separation was highest in mandibular molars followed by maxillary molars [13]. Similar to earlier clinical studies, instrument separation occurred more often in the apical third region, followed by the middle region, and least in the coronal third region [2,12] in the current study [2,13]. A study from Türkiye reported that the frequency of file separation was higher in the mesiobuccal canal and apical one-third of the root canal. They also reported separation to be frequent in teeth with moderate to severe curvature (82%) which is similar to the current study (84%) [12].

Another interesting aspect seen in the current study was the length of the separated instrument. Earlier laboratory studies indicated that the length of SEI was mostly below 5 mm, but contrary to this, SEI longer than 5 mm were also noticed. In 18% of the cases, SEI was

Table 3. Logistic regression: various prognostic factors influencing the instrument retrieval

Variable	B	SE	Wald	df	*p*-value	Exp(B) (95% CI)[a]
Position of the tooth (Ref, anterior)	0.585	1.105	0.280	1	0.597	1.795 (0.206–15.654)
Arch (Ref, maxillary)	0.649	0.869	0.558	1	0.455	1.914 (0.349–10.503)
Curvature (Ref, mild)	–0.070	0.845	0.007	1	0.934	0.933 (0.178–4.885)
File size (cont)	–0.044	0.068	0.406	1	0.524	0.957 (0.837–1.095)
Taper (cont)	0.401	0.176	5.222	1	0.022	1.494 (1.059–2.107)
Level of the separated instrument (Ref, coronal 2/3rd)	2.170	0.877	6.120	1	0.013	8.761 (1.570–48.901)
Length of file (Ref, <5 mm)			0.215	2	0.898	
If length is 5–10 mm	0.390	0.848	0.212	1	0.645	1.477 (0.281–7.780)
If length is >10 mm	0.218	1.321	0.027	1	0.869	1.243 (0.093–16.562)
File type (Ref, conventional files)	–0.649	0.659	0.971	1	0.324	0.523 (0.144–1.900)
Constant	–4.618	2.241	4.246	1	0.039	0.010

CI, confidence interval; df, degree of freedom; SE, standard error.
[a]Odds of failure to retrieve the instrument.
cont: Age, taper of the instrument and file size were considered as continuous variable.
The reference category (Ref) used for the seven categorical variables was mentioned in the parentheses.

Table 4. Bootstrapped logistic regression

Variable	B	Bootstrap[a]			
		Bias	SE	*p*-value (2-tailed)	95% CI
Arch	0.649	1.719	13.010	0.513	–1.994 to 21.786
Curvature	–0.070	–0.296	11.443	0.901	–4.410 to 12.313
File size	–0.044	0.053	0.724	0.471	–0.262 to 0.266
Taper	0.401	0.693	6.385	0.011*	0.045 to 1.643
Level of the separated instrument	2.170	6.217	23.690	0.002*	0.945 to 41.991
Length of file (5–10 mm)	0.390	0.473	12.514	0.632	–2.985 to 3.998
Length of file (>10 mm)	0.218	–4.096	16.871	0.516	–22.767 to 20.726
File type	–0.649	–0.100	9.020	0.373	–3.690 to 1.353
Constant	–4.618	–15.843	86.317	0.038	–70.911 to –0.487

CI, confidence interval; SE, standard error.
[a]Bootstrap results are based on 1,000 bootstrap samples.
*$p < 0.05$.

seen to include multiple levels (corono-apical, middle-apical) and in 5% of the cases, it occurred along the entire length of the root canal. This could have probably been due to excessive torsional loading [20]. Longer fragments could pose additional challenges to retrieval in the form of secondary fracture, which necessitated more chair side time and additional dentin removal to retrieve these fragments [21]. The pattern of instrument separation was also similar between conventional NiTi files and newer generation heat-treated NiTi files.

Retrieval was successful in 79.5% of cases in the current clinical study, which was similar to the success rate reported for retrieval of broken instruments using ultrasonics alone in a previous study [22]. This is slightly lower than the values reported by Malentacca *et al.* (83%) [17] and Fu *et al.* (88%) [4]. While Fu *et al.* [4] used the same staging platform (Ruddle's technique) as the current study, Malentacca *et al.* [17] used a modified spinal tap needle for the retrieval of hand files. Another study by Nevares *et al.* [23] reported a lower success rate of 33% for retrieving SEI in 112 of their cases using the Ruddle's technique. Retrieval in that study was done, only if the separated fragment was visible under the microscope. The higher success rate for retrieval in a study by Cuje *et al.* (95%) [24] is attributed to the fact that 52% of the instruments retrieved were stainless steel instruments. In contrast, in the present study, the vast majority were NiTi rotary instruments, excluding eight cases

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which were stainless steel files. Ward *et al.* [25] reported a success rate of only 67% and the authors attempted retrieval under a dental operating microscope but used CPR (controlled penetration removal) ultrasonic tips. Souter and Messer [26] reported a success rate of 70% for retrieval of hand and rotary instruments which is slightly lower than the current study. The difference in success rates for retrieval among studies might have occurred, due to different ultrasonic tips, varied techniques used, and also the operator skill. The retrieval in the current study was attempted by a senior endodontist, who had prior training in instrument retrieval. If multiple operators were to be involved in retrieval attempts, the success rates could differ and this needs to be studied in the future.

The length of the SEI has not been taken into consideration in previous studies, 11% of longer SEI underwent secondary fracture and this further increased the retrieval time. Longer fragments were successfully removed using a combination of ultrasonics and looping techniques in 80% of the cases. This method can decrease the treatment time and reduce the incidence of secondary fractures. According to Terauchi *et al.* [27], any SEI, longer than 4.5 mm can be removed easily using looping systems. The BTR loop device was used for retrieval in this study. This device allows for a loop of 0.5 mm diameter to be used inside the root canal.

Ultrasonic ET 40 and 20 tips (Acteon Endo Success tips, Eighteeth Medical Ultra X Tip; distributed by Orikam Healthcare, India) were used during the first 5 years of the study. During the next 5 years, the Terauchi file retrieval kit's ultrasonic tips 87,88, and 89 (Dental Engineering Laboratories) were used, as these tips allowed for precise dentin removal due to their longer and smaller dimensions. Besides this U files sizes 15 and 20 (Mani Inc.) were used in select cases to free the separated instrument from dentin if the file was not retrieved using the former ultrasonic tips. The most common iatrogenic error that occurred was the fracture of the ultrasonic tip itself, which occurred in 15 cases, but all of those were removed easily using ultrasonic vibrations with larger tips. But the chair side time was increased in all cases. In 11% of the cases, the SEI itself underwent a secondary fracture, which was also removed subsequently. The other iatrogenic errors that occurred, were perforation and ledge formation which occurred in one case each and were managed accordingly.

Among the various factors influencing instrument retrieval, the taper and apical positioning of the SEI were the ones that negatively impacted instrument retrieval [21]. The chances for failure to retrieval is 1.4 times more with every increase in taper. Previous studies have reported more fracture in files with larger taper than in files with smaller taper, due to increased stress intensity at the point of flexure [28]. The increased cross-section of the file will limit the potential space available for ultrasonic vibrations and also hamper the enveloping of the instrument using the looping device.

Failure to retrieve was eight times more if the files were placed apically. Two earlier studies have reported difficulty and inability to retrieve instruments separated in the apical third [25,26]. Similarly, Dioguardi *et al.* [29] in their trial sequencing analysis reported that increased failure rates were seen when instruments were located more apically when compared to middle and coronal thirds. The narrow dimensions of the root canal and lack of clear visibility of the SEI make retrieval difficult in the apical portion of the root canal. Besides this, clinicians often limit the use of ultrasonic instruments in the apical portion for fear of perforation [25,26].

The use of the gold standard 'Ruddle's technique' for retrieval has proven effective and successful based on the previous literature and in this current study [4,23]. It is important to highlight that the newer generation heat-treated NiTi files can be retrieved similarly to the conventional NiTi files using the current microscopic instruments. In the vast majority of cases, the retrieval was done in a single appointment, but in a few cases multiple appointments were required and this extended chair side time required for retrieval could pose a problem in pediatric or geriatric patients. While most of the separated instruments in this study could be retrieved, the process requires significant time and resources. Therefore, clinicians should take extra precautions to prevent SEI from occurring. Special care is essential during instrumentation in root canals, particularly in posterior teeth of the mandibular arch and in teeth with moderate to severe curvature.

The study has certain limitations, including a small sample size and the fact that all retrieval procedures

were conducted by a single operator, which affects the generalizability of the findings. While the evidence presented is classified as observational, conducting a clinical trial on this issue would have posed significant challenges. Nonetheless, the credibility of the results remains intact. Given that only one trained endodontist performed the retrievals, varying success rates might be observed with multiple operators. Therefore, future research should focus on larger sample sizes, involve multiple operators, and explore the impact of different motion kinematics, such as reciprocation.

CONCLUSIONS

SEI was more frequently observed in the mesiobuccal roots of mandibular and maxillary molars with moderate curvature. Instrument separation occurred more frequently in the apical portion of the root canal. There was no difference in the pattern of SEI between the conventional NiTi and newer generation heat-treated NiTi files. The great majority of cases had successful instrument retrieval. The instrument taper and apical location of the SEI had a negative impact on instrument retrieval.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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AUTHOR CONTRIBUTIONS

Conceptualization, Data curation, Investigation, Methodology, Project administration, Resources, Software, Visualization: Natanasabapathy V, Varghese A, Karthikeyan PKA. Formal analysis, Validation: all authors. Supervision: Natanasabapathy V, Varghese A. Writing - original draft: all authors. Writing - review & editing: Natanasabapathy V, Varghese A, Karthikeyan PKA. All authors read and approved the final manuscript.

DATA SHARING STATEMENT

The datasets are not publicly available but are available from the corresponding author upon reasonable request.

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