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Corrosion in Stainless-Steel and Nickel-Titanium Files

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This study evaluated and compared the corrosion susceptibility of stainless-steel and nickel-titanium (NiTi) endodontic files immersed in sodium hypochlorite. For each of the stainless-steel files (Kerr K-Flex, Caulk Flex-O, and Union Broach Flex-R) plus the NiTi files (Union Broach NiTi and Tulsa NiTi), the cutting flutes of 24 ISO size 20 files were immersed into 5.25% sodium hypochlorite. Their open circuit potential (OCP) was recorded for 1 h on a strip chart with high impedance. The strip chart recording for each file was classified into a stability score: (i) stable, (ii) unstable, or (iii) erratic. The OCP was measured by a potentiostat and a standard calomel electrode reference. The OCP classification of unstable and erratic for the files evaluated were as follows: K-Flex (16%), Flex-R (12%), Flex-O (75%), Union Broach NiTi (62%), and Tulsa NiTi (0%). After OCP testing, each of the 120 files was inspected by light microscopy at ×25. The frequencies of visually observed corrosion were detected as follows: K-Flex (2/24), Flex-R (1/24), Flex-O (6/24), Union Broach NiTi (2/24), and Tulsa NiTi (0/24). There was a significant difference in corrosion frequency between brands when evaluated by OCP and light microscopy; however, there was no significant difference between stainless steel and NiTi.

Root canal therapy involves a variety of instruments used in conjunction with various irrigating solutions for chemomechanical cleaning and shaping procedures. The chemical effects of irrigating solutions on endodontic files may hinder their performance. Corrosion adversely affects metallic surfaces by causing pitting and porosity, and decreases the cutting efficiency of endodontic files.

Mueller (1) demonstrated that electrochemical techniques based on polarization profiles and polarization resistance methods are efficient and reliable to study the mechanisms of corrosion of endodontic instruments and to judge the corrosion susceptibility of newly developed and improved materials for instrument usage. Neal et al. (2) studied the effect of sterilization and irrigants on the cutting ability of stainless-steel files. Files treated with sodium hypochlorite (NaOCl) showed a brown corrosion product.

Procedural errors can occur during the instrumentation of curved canals that may alter the shape of the canal and the apical foramen (3). It has been shown that there is a substantial rise in instrument stiffness with increasing file size of stainless-steel files (4). Manufacturers have marketed a number of new stainless-steel files based on different cross-sectional shapes, design concepts, and fabrication procedures, in a quest for improved cutting efficiency and flexibility.

Walia et al. (5) were the first to report the use of an entirely new, highly flexible, metallurgical system: Nitinol (nickel-titanium (NiTi)) orthodontic wire alloy, for the fabrication of endodontic files. Edie et al. (6) showed that Nitinol (NiTi) and stainless-steel wires have similar resistance to corrosion under clinical conditions, but Nitinol is much more flexible.

Aten (7) tested eight different endodontic file brands, using simulated clinical situations combining angular deflection stress, chemiclave sterilization, and exposure to NaOCl. His results showed that K-Flex and Flex-R files showed the most corrosion (7). Scott et al. (8), in a follow-up study, tested Kerr K-Flex and Caulk Flex-O-Files. They found that all of the Caulk Flex-O-files showed corrosion near the junction of the handle and shaft, and none of the Kerr K-Flex files corroded (8). Barss et al. (9) evaluated the corrosion susceptibility of Kerr K-Flex, Caulk Flex-O-file, and Union Broach Flex-R files (9). The results of this study showed that the Kerr K-Flex files corroded more than Caulk Flex-O-Files and Union Broach Flex-R files (9). Barss et al. (9) also demonstrated that, within a new pack of unstressed stainless-steel files, some would corrode, whereas others would not when exposed to 5.25% NaOCl. This corrosion would begin within 6 to 15 min and was easily detected by open circuit potential (OCP) (9).

The purpose of this study was to evaluate and compare the corrosion susceptibility of stainless-steel and NiTi endodontic files immersed in NaOCl by OCP and visual microscopic examination.

MATERIALS AND METHODS

Five file brands were used for this study: Kerr K-Flex, stainless-steel (Kerr Manufacturing Company, Romulus, MI), Caulk Flex-O-File, stainless steel (L. D. Caulk Division/Dentsply, Milford,

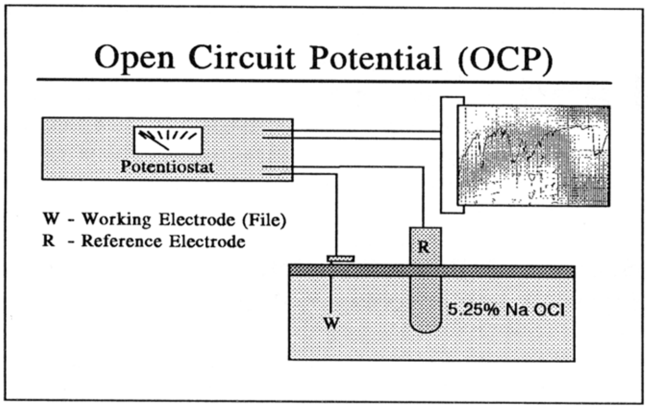

FIG 1. Schematic of apparatus to measure OCP.

DE), Union Broach Flex-R stainless-steel (Moyco Union Broach, York, PA), Union Broach NiTi (York, PA), and Tulsa NiTi K-Files (Tulsa Dental Products, Tulsa, OK). The 25 mm length ISO size 20 file was selected for each brand in this study. One hundred and twenty files (24 from each group) were used.

The files were immersed in 5.25% NaOCl and the OCP was recorded for 1 h on a strip chart with high impedance (Perkin-Elmer Recorder 56, Hitachi, Ltd., Tokyo, Japan). A saturated calomel electrode (SCE) was used as the reference electrode (Fig. 1). The OCP was measured by the Potentiostat/Galvanostat model 263 (EG+G Princeton Applied Research). OCP is the potential between a file and the SCE while immersed in solution.

Each file, after being immersed in 5.25% NaOCl for 1 h at room temperature, was rinsed in water and allowed to dry at room temperature on filter paper. The files were stored individually in glass vials (Kimble Glass, Inc., Toledo, OH). The strip chart recording for each file was classified into a stability score: (i) stable (plateau level of several hundred millivolts that remained there for 1 h), (ii) unstable (small or irregular millivolt jumps in 1 h), or (iii) erratic (large, erratic jumps of several hundred millivolts in 1 h) (Fig. 2).

After 1 h immersion, a random blind examination was conducted for each file for visual signs of corrosion. This allowed for each file to be examined without knowing the file type, brand, or stability of its OCP. Each of the 120 files were inspected with an Olympus microscope and camera at ×25. Files were photographed only when corrosion was detected. Each file was judged and ranked according to the following criteria: 0, no corrosion; 1, mild corrosion (surface pitting with no discoloration); 2, moderate corrosion (pitting with corrosion products); and 3, severe corrosion (pitting corrosion and metal separation).

The stainless-steel file (study file #58) that demonstrated the most corrosion along with the NiTi file (study file #114) that demonstrated the most corrosion was examined under the scanning electron microscope (SEM) (model S10, Cambridge, UK). Energy dispersive spectrometery (EDS) was also conducted on these two files. The SEM was used to visualize the effect of corrosion on these two selected endodontic files. EDS was used to determine the components of the endodontic file alloy in corroded and noncorroded areas.

The statistical analysis of visual corrosion and stability was done with the Kruskal-Wallis ANOVA and the Mann-Whitney *U* test. Analysis of the OCP was done by ANOVA. The independent variables used were materials (stainless-steel versus NiTi) and

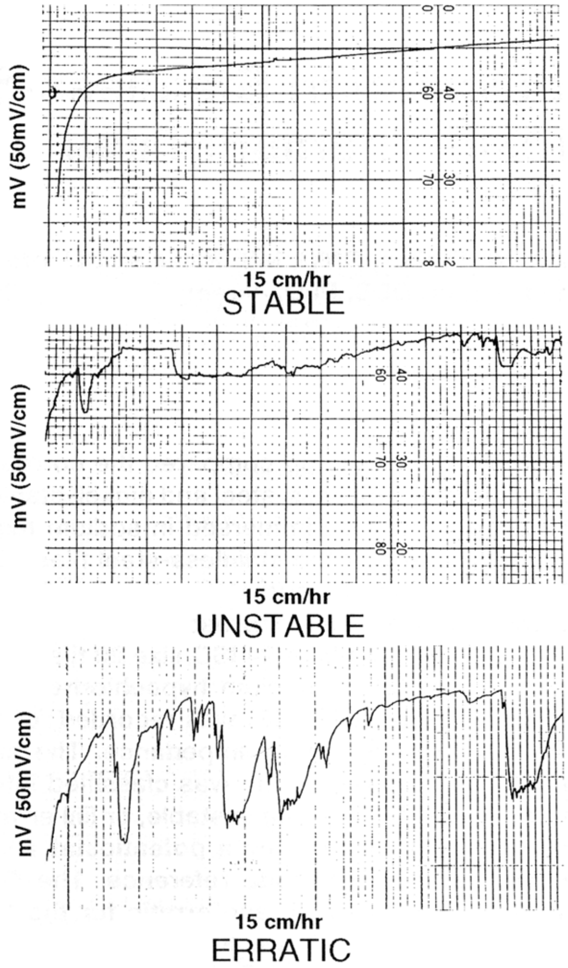

FIG 2. Classification of stability scores in mV for 1 h.

RESULTS

Results showed the following percentages of corrosion for each file. Visual signs of corrosion: K-Flex (8%), Flex-R (4%), Flex-O (25%), Union Broach NiTi (8%), and Tulsa NiTi (0%). Unstable and erratic OCP: K-Flex (16%), Flex-R (12%), Flex-O (75%), Union Broach NiTi (62%), and Tulsa NiTi (0%) (Table 1).

Data analysis showed that material had no effect on the dependent measures of corrosion, and brand had a significant effect on all three dependent variables. A relationship was noted between the three dependent variables. The results are summarized in Table 1.

Brand had a significant effect on all three dependent variables. Barss et al. (9) noted a possible connection between corrosion and stability of OCP (9). To use OCP as a measure of corrosion, the relationship between visual corrosion and stability was examined. Although these variables are closely correlated, this study was unable to demonstrate a 1:1 relationship between OCP stability and corrosion.

Of 120 files, 80 files that exhibited a stable OCP showed no visual signs of corrosion. Five files showed visual corrosion and had an unstable OCP, and six files showed corrosion and had an erratic OCP. However, 29 files had an unstable or erratic OCP but

TABLE 1. Visual signs of corrosion and OCP stability in percentage

Brand	Visual Corrosion	Stability			RowTotals
		Stable	Unstable	Erratic	
K-Flex	None	(84%) 20	(8%) 2	(0%) 0	(92%) 22
K-Flex	Minimal	0	0	0	0
K-Flex	Moderate	0	(4%) 1	(4%) 1	(8%) 2
	Total	(84%) 20	(12%) 3	(4%) 1	(100%) 24
Flex-R	None	(88%) 21	(8%) 2	(0%) 0	(96%) 23
Flex-R	Minimal	0	(4%) 1	0	(4%) 1
Flex-R	Moderate	0	0	0	0
	Total	(88%) 21	(12%) 3	(0%) 0	(100%) 24
Flex-O	None	(25%) 6	(29%) 7	(21%) 5	(75%) 18
Flex-O	Minimal	0	(4%) 1	(13%) 3	(17%) 4
Flex-O	Moderate	0	(8%) 2	0	(8%) 2
	Total	(25%) 6	(41%) 10	(34%) 8	(100%) 24
Tulsa	None	(100%) 24	0	0	(100%) 24
Tulsa	Minimal	0	0	0	0
Tulsa	Moderate	0	0	0	0
	Total	(100%) 24	0	0	(100%) 24
Union Broach	None	(38%) 9	(50%) 12	(4%) 1	(92%) 22
Union Broach	Minimal	0	0	(8%) 2	(8%) 2
Union Broach	Moderate	0	0		0
	Total	(38%) 9	(50%) 12	(12%) 3	(100%) 24
	Column total	80	28	12	120

SEM Results

Photographs and SEMs (Fig. 3) of study file #58 demonstrated the greatest amount of corrosion observed among the stainless-steel files. EDS of this file showed the components of the file alloy in the noncorroded (Fig. 4) and corroded areas (Fig. 5). There was a depletion of chromium in the corroded area (Fig. 5).

Of the NiTi files, study file #114 exhibited the greatest amount of corrosion. This file was photographed at ×25 and examined under SEM (Fig. 6). EDS was also conducted. Unlike the results for the stainless-steel file, the EDS did not show a difference in the file alloy in the noncorroded and corroded areas for the NiTi file.

DISCUSSION

This study had two purposes: (i) to examine the corrosion effect of 5.25% NaOCl on stainless-steel and NiTi files using five brands of endodontic files and (ii) to examine whether OCP stability could be used as a measure of corrosion. No relationship between the alloy material and corrosion was found. However, brand did have an effect. The difference between brands could possibly be due to variations in the manufacturing process and quality control. Often, both corroding and noncorroding files were present in the same package.

Presently, there is little information concerning the corrosion of NiTi files, but the results of this study reinforce the conclusions of

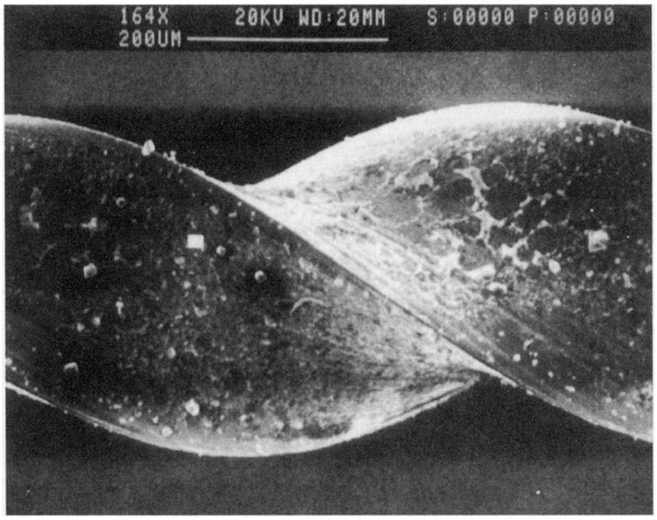

FIG 3. SEM of stainless-steel study file #58 demonstrating corrosion at ×164.

tance to corrosion under clinical conditions (6). According to visual analysis of corrosion, the following ranking of corrosion resistance under these test conditions, from best to worst was: (i) Tulsa NiTi, (ii) Union Broach Flex-R, (iii) Kerr K-Flex, (iv) Union

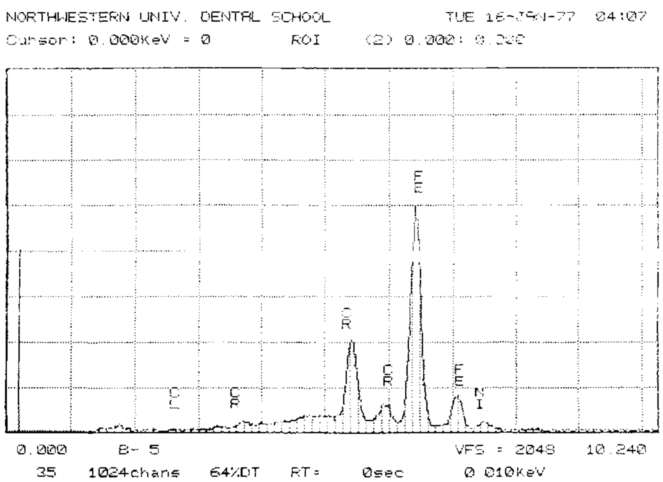

FIG 4. EDS results from a noncorroded area of stainless-steel study file #58 showing base-line chromium level.

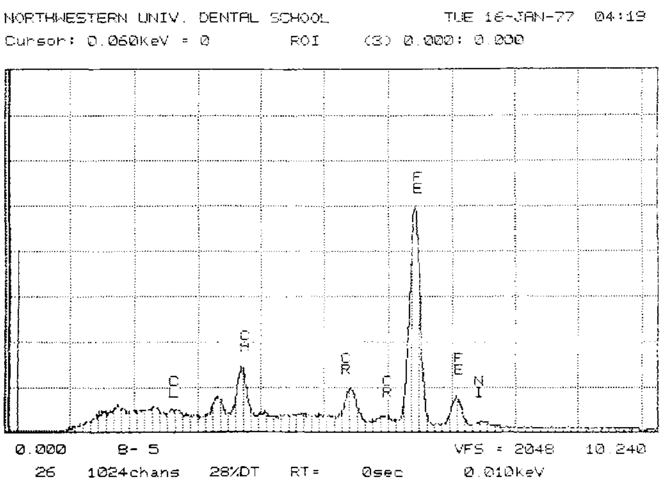

FIG 5. EDS results for corroded area of stainless-steel study file #58 showing depleted chromium level.

There are several electrochemical tests that are used to assess the corrosion properties of alloys. These tests typically investigate the current potential characteristics of the metal–solution interface. OCP represents the potential at which all oxidation and reduction reactions are occurring simultaneously (10). In this study, 29 of the total 120 files had an unstable or erratic OCP, but showed no visual corrosion. This could mean that corrosion was present in the files with unstable OCP, but was subtle enough that it could not be detected at ×25.

It is important to determine what manufacturing factors affect corrosion of endodontic files. However, information on endodontic

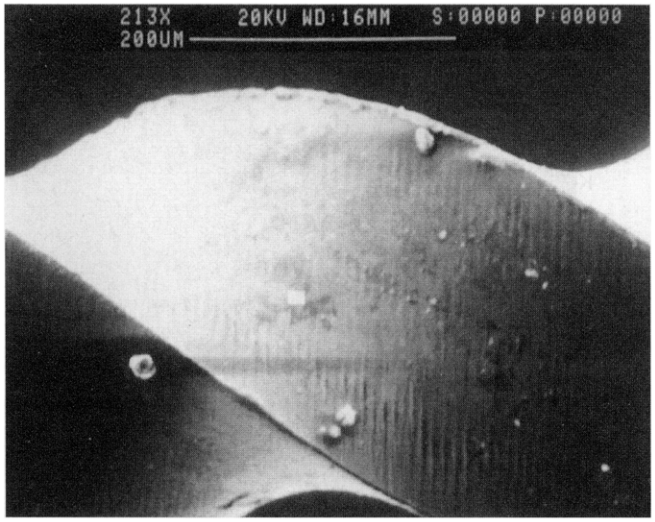

FIG 6. SEM of NiTi study file #114 demonstrating corrosion at ×213.

file production procedures is proprietary. Therefore, OCP stability could be promising as a quality control measure of corrosion, but further study is needed to establish a definite relationship.

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