DETERMINATION OF FRACTURE PATTERNS OF A BRAND OF STAINLESS STEEL K FILES; AN IN VITRO STUDY

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ABSTRACT

Objective of the study was to qualitatively determine and compare the fracture patterns of hand held stainless steel K files (Mani, Inc. Japan), acquired from Pakistan and United Kingdom. This study was conducted at the Institute of Space Technology, over a period of one month.

A total of 40 stainless-steel K files (Mani, Inc. Japan) of identical size (ISO#25) were collected and divided into two groups, such that Group A consisted of 20 K files acquired from the Rawalpindi/ Islamabad region in Pakistan while Group B consisted of 20 K files that were purchased from London, UK. The files were fractured one by one, 3mm from the tip. The fractured surfaces were then observed under scanning electron microscope to determine their fracture patterns.

Evaluation of the fractured surfaces revealed decreased ductility in Group A in comparison with Group B.

Stainless steel endodontic files available commercially in Pakistan need evaluation of their fracture behavior for patient safety and benefit.

Key Words: *Stainless steel endodontic K files, fractography, ductility, brittleness.*

INTRODUCTION

The fracture of an instrument is a discerned complication in endodontics.[1] Predominant modes of endodontic instrument fracture are commonly recognized as torsional and flexural.[2] Torsional fractures occur when a part of the instrument becomes lodged in the canal wall, leading to torsional overload because of friction, while flexural fatigue occurs due to generation of tension/compression cycles as the instrument rotates in a curved canal files.[2] Many factors have been associated with the susceptibility to fracture of endodontic instruments including tip design, taper, machining defects, manufacture processes, alignment of the root canal, operator proficiency and frequency of use.[2] Preponderance of the literature concerned with the instrument failure is in vitro evidence, which confines its clinical significance.[3]

Yao, JH et al analyzed the fracture patterns of three types of rotary endodontic instruments and concluded that diverse cross-sectional configurations, diameters, and tapers, all subsidize the instrument's susceptibility to cyclic fatigue.[4] Kim, H.-C., et al., discovered that files with machining grooves may have a higher risk of fracture.[5] Kazemi and Stenman reported brittle fracture as the predominant mode in their investigation of specimens of stainless steel files, qualitatively observed by scanning electron microscope.[6]

Pruett, J.P., et al., established that nickel-titanium files can fracture without any visible weaknesses or permanent deformation, unlike stainless steel files that display discernible signs of deformation before fracture.[7] Moreover, it was established that nickel-titanium instruments have reduced hardness, wear resistance and cutting efficiency as compared to stainless steel instruments.[8] However, due to its varied range of elastic deformation, Ni Ti alloy may be strained much further than stainless steel before it is permanently deformed.[8] Therefore, based on the in-vitro literary evidence, it may be recognized that the incidence of fracture of Ni Ti files is lower than that for stainless steel hand held files.[9-15] This may be attributed to the fact that stainless steel instruments have a tendency to straighten in curved canals owing to their reduced flexibility.[1]

Commonly, fracture patterns in metals are categorized as either brittle or ductile. Ductility denotes to the capacity of a material to absorb energy prior to failure, while brittle failures are concomitant with little

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or no plastic deformation, plus low energy absorption before breakage. Therefore, brittle failures commonly ensue in metals with reduced ductility.[16]

A number of causative factors have been mentioned in the literature for catastrophic failure of endodontic instruments, such as clinical misuse and/or overuse, inherent flaws in the files along with non-standardized forms, induced weaknesses due to machining errors, and reduced ductility. However, no one causative factor has conclusively accounted for their seemingly random failures.[17] It is therefore vital for the clinician to recognize the probability of instrument failure and the underlying causes for this disadvantageous occurrence. The importance of material selection based on favorable chemical and physical properties, stress limitation and a controlled working environment cannot be over emphasized.[2]

Fractographic analysis at finer level is routinely carried out using a scanning electron microscope.[18] Primary objective of fractographic inspection is to ascertain the root of breakage by analyzing the features of a fractured surface. Diverse nature of crack growth gives rise to distinctive features on the surface which can be interpreted to discern the fracture mode. The purpose of this study was to qualitatively determine and compare the fracture patterns of a brand of hand-held stainless steel K files (Mani, #25), acquired from Pakistan and The United Kingdom. The prevalent sale of non-standardized stainless steel endodontic files in the Pakistani market makes it extremely important to assess their fracture behavior for patient benefit and safety.

METHODOLOGY

In order to determine and compare the fracture patterns of the files of Groups A and B, samples were prepared by gripping each file successively with a plier at a distance of 3mm from the tip. The plier was secured in a vice. At the other end, the handle of each file was gripped by another plier and carefully rotated clockwise until fractured. The files were then secured upright in a holder and their fractured surfaces were analyzed using scanning electron microscope (TESCAN Mira-3; Field emission scanning electron microscope. Czech Republic. High resolution imaging, 1.2nm at 30 kV; magnification range, 2x to 10,000,00x) to ascertain the predominant mode of fracture at 1kX, 2Kx and 5kX.

RESULTS

All the files belonging to Group A showed a similar behavior in terms of fracture. The fractured surfaces of the specimens showed a dimpled pattern in the middle regions at 1kX, indicating a ductile fracture, as can be seen in Fig 1. The high magnification image of the mid region at 5 kX further confirmed the findings, as shown in Fig 2. However, flatter surfaces towards the edges of the specimens were observed at 2kX and 5kX, as can be seen in figures 3 and 4. These flat surfaces at the edges indicate towards a decrease in ductility.

On the other hand, all the files belonging to Group B showed comparably a uniform appearance of fractured surfaces. The mid regions showed a ductile pattern at 1kX as can be seen in Fig 5, the finding being confirmed by the high magnification image at 5kX shown in Fig 6. However, unlike group A, the decrease in ductility was much less pronounced towards the edges at 2kX and 5kx, as shown in Fig 7 and 8. A dimpled appearance, indicative of a ductile fracture, was seen throughout the fractured surface of the specimens in Group B, being more accentuated in the mid regions.

DISCUSSION

In this study, files in Group A revealed propensity towards brittleness, while files in Group B showed a more ductile pattern similar to Kazemi's observations.[6] Ductile fractures are characterized by the occurrence of necking which is followed by the formation of micro voids in the metal. Nucleation, growth, and micro void amalgamation ultimately debilitate the metal, leading to failure, often resulting in a cup and cone shaped fractured surface. Plastic deformation because of slip, the process by which a dislocation moves in response to shear stresses, contributes to ductile fracture through crack propagation across the grain boundaries (transgranular).[19] The fracture surface subsequent to this mechanism is commonly categorized by a dimpled configuration. The shape and inclination of the dimples may point towards the type of load exerted and

TABLE1: DETAILS ABOUT THE MATERIAL USED FOR TESTING

Sources (countries)	Type of files	No. of files	Manufacturer	Lot number	Groups assigned
Pakistan (Rawalpindi/Islamabad)	Stainless steel K files, 21mm #25	20	MANI, INC. 8-3 Kiyohara Industrial Park. Utsunomiya, Tochigi. Japan	R151412100	Group A
United Kingdom (London)	Stainless steel K files, 21mm #25	20	MANI, INC. 8-3 Kiyohara Industrial Park. Utsunomiya, Tochigi. Japan	R110868200	Group B

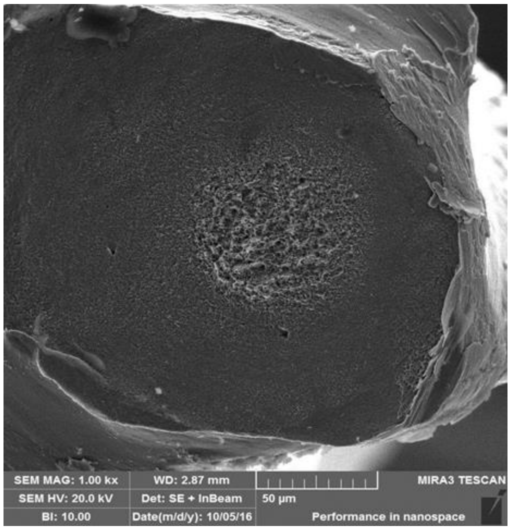

Fig 1: Mid region of a Group A file with a dimpled appearance

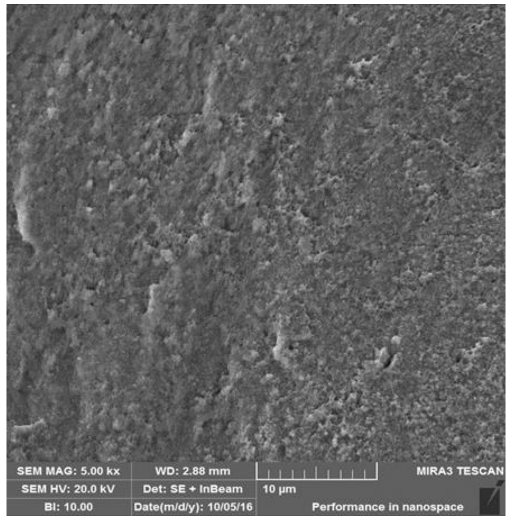

Fig 4: High magnification image of a group A file showing a flatter surface in the peripheral region than the mid region

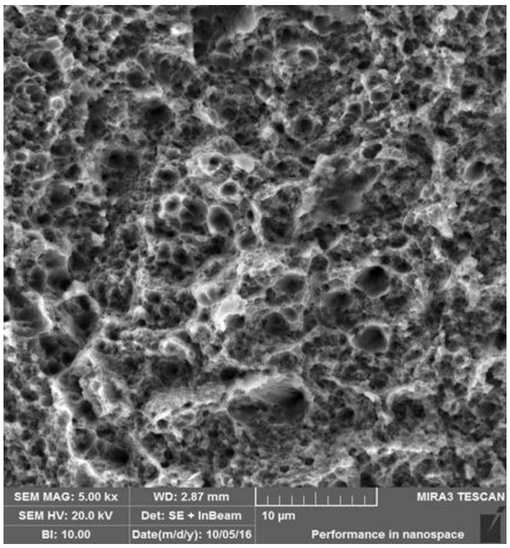

Fig 2: High magnification image of the mid region of Group A file confirming the presence of dimples

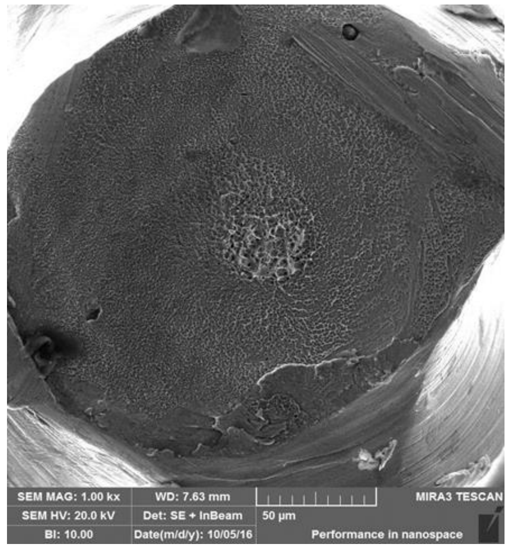

Fig 5: Mid region of a Group B file showing a dimpled surface

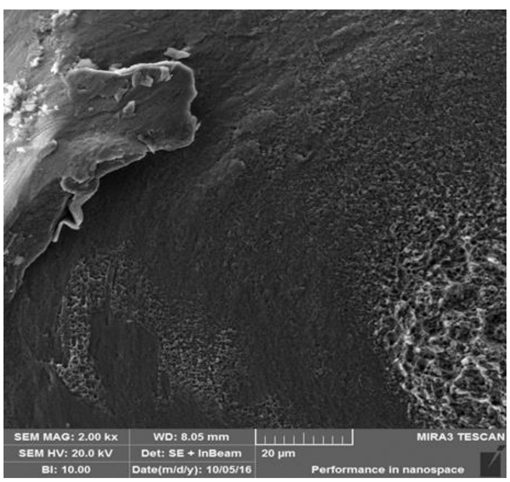

Fig 3: Peripheral region of a Group A file showing a flatter surface

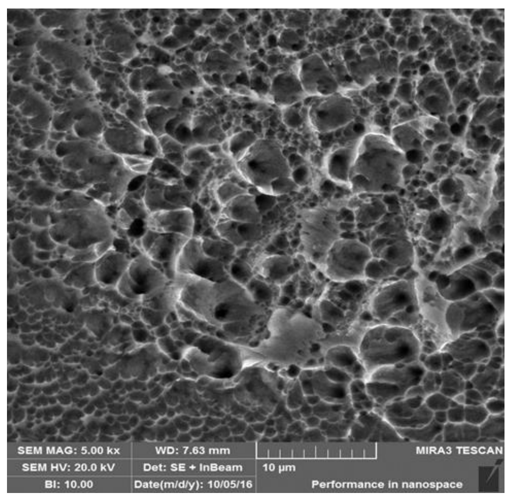

Fig 6: High magnification image of the mid region of Group B file showing dimples

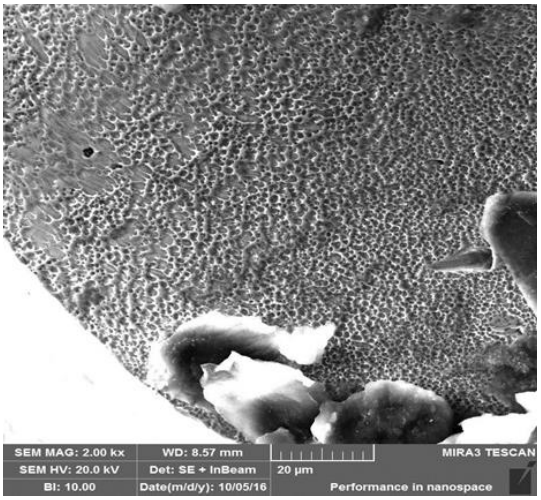

Fig 7: Peripheral region of a Group B file having a dimpled appearance

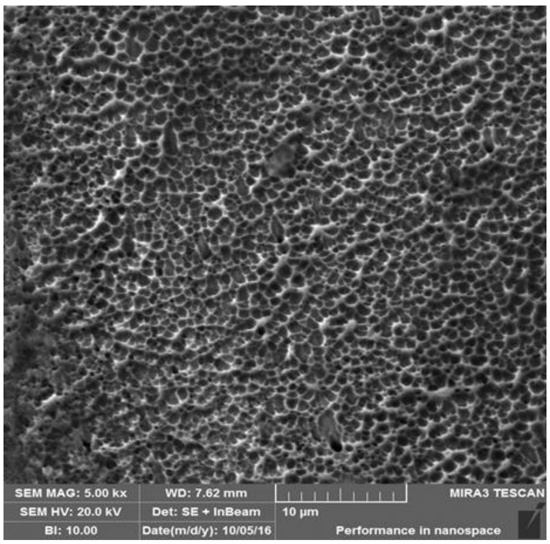

Fig 8: High magnification image of peripheral region of a Group B file showing dimples

also the cause of fracture. For example, round dimples are suggestive of separation being induced by tensile forces, whereas oval or elongated dimples advocate shear forces. Crack growth ensues gradually as the extent of the crack propagates. Frequently labeled a stable crack, as it will not further propagate without the application of additional stress.[19]

In brittle fracture, cracks run perpendicular to the applied stress which results in a relatively flat surface at the break. Characteristically there is an initiation of crack at the surface of the metal, which may propagate either along grain boundaries (intergranular) or between specific crystallographic planes (cleavage), due to stress concentration at the base of the crack.[20] According to Griffith's theory brittle materials comprise minor cracks and defects.[21] These defects perform as stress raisers, cumulating the localized stresses around sharp edges. Fracture occurs when the localized stress surpasses the material's cohesive strength. Hence, the relatively brittle nature of the locally available Group B files may be because of some minor defects incorporated during manufacturing process. Further studies on surface topography of the files may give an insight on the exact mechanism causing brittle failure of these files.

Due to limitation of time and resources, a standardized torsional machine could not be set up for the breakage of files to determine their fracture patterns. The type of method used in this context, however, is not very significant since the fracture behavior of a material is generally governed in large by the rate of strain induced in it. A material that is inherently ductile will remain ductile and vice versa, unless the strain rate is altered by multiple orders of magnitude.[22] For a ductile material to show brittle behavior, the minimum amount of stain rate induced in it has to be as high as 10^3 s^{-1}, as is done in impact testing.[22] In our study, however, the maximum strain rate induced in the instruments, calculated by the formula, was approximately 10^{-2} s^{-1}. Hence, for the instruments to show a transition from ductility to brittleness, the order of magnitude in our study would have had to be increased up to 10^5 s^{-1} (a million times), which is extremely unlikely by manual force application. Therefore, the stress applied or the number of cycles to failure of the instrument becomes insignificant in this case, since physically it is not possible to bring about a change in strain rate of a material by such high orders of magnitude.[22]

This particular phenomenon related to strain rate has been explained in a study conducted by Hossain, A., et al., in which the effect of different strain rates on fracture behavior of various alloys was tested by means of a tensile test machine. In their study, in spite of automated increase in strain rate from 10^{-4} s^{-1} to 10^{-2} s^{-1} (200 times), the change in ductility was almost negligible.[23]

A fractured instrument restricts access to the apical portion of the canal, compromising cleaning and shaping. An effort to circumvent a broken file should primarily be weighed up, as it may be ineffective.[9] Prognosis may be undermined if file fracture ensues in the initial phases of canal shaping without at least minimal debridement, and the instrument cannot be bypassed.[24] Conversely, prognosis may be satisfactory in scenarios where canals have been sufficiently cleaned, resulting in adequate microbial elimination, where larger files have separated in the apical third or where the fractured piece has been adequately bypassed.[24] Though it is better to remove the piece and pursue treatment under ideal circumstances, this is not always possible. The perils of removal should be weighed up against the benefits as weakening of the tooth or perforation during instrument removal may be more damaging than the fragment of instrument.[1]

In metallurgical failure, the synergy of the environment, forces and an alloy can be rather intricate.[22] In this regard, several dynamics are elaborated in the breakage of endodontic instruments and it is challenging to identify only one element. Due to diversity of the canal configurations and factors influencing separation, it is difficult to predict when the instrument will fracture. Single use is therefore recommended for complete safety.[25]

CONCLUSION

Locally acquired files revealed a higher degree of brittleness relative to the international ones. Thorough evaluation of the surface topography as well as simulated clinical studies on torsional properties of the stainless steel endodontic files is required to better understand their fracture dynamics.

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CONTRIBUTIONS BY AUTHORS

1 **Maryam Saeedullah:** The main idea in the study belongs to Author 1. She designed the study models and conducted the practical tests for data collection. Moreover, she has written the article.

2 **Syed Wilayat Husain:** Helped in arranging all the necessary equipment required for the testing purpose. He supervised the projects and contributed towards devising established methodological approaches for the study. He also helped with the statistical analysis.