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Incidence of Vertical Root Fracture at the Apical Third of the Root Canal System after Preparation with Newer NiTi Rotary Files and Hand Files at Different Working Lengths

A Thesis

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Abstract

Introduction

Vertical root fracture (VRF) is considered one of the most unfavorable complications in root canal treatment which may lead to tooth extraction. The aim of the study was to compare the incidence of generation of dentinal defects in the apical third of human extracted teeth after canal preparations with new rotary files (Vortex blue rotary file and HyFlex CM file) at different instrumentation lengths after hand filing vs. hand filing only (K-Flexofile). At different levels, the assessment of the defects was evaluated using a stereomicroscope using a cold light source.

Materials and Methods

One hundred and twenty anterior teeth (maxillary and mandibular) were mounted in resin blocks with simulated periodontal ligaments after examination and exclusion of cracked teeth. The teeth were randomly divided into six groups (N = 20). Group 1: Control group (no preparation). Group 2: Hand file to working length using Stainless steel K-Flexofile (Dentsply Maillefer, Ballaigues, Switzerland). Group 3: Hand file to working length and Vortex Blue rotary file (Dentsply, Tulsa, OK) to working length. Group 4: Hand file to working length and Vortex Blue rotary file to -2 mm of the working length. Group 5: Hand file to working length and HyFlex CM file (Coltène Whaledent, Cuyahoga Falls, OH, USA) to the working length. Group 6: Hand file to working length and HyFlex CM file to -2 mm of the working length. Specimens were sectioned horizontally at 2 mm from the apex and dentinal microcracks were observed under a

stereomicroscope. The differences between groups were determined by Fisher's exact test.

Results

The control group did not show any dentinal defects. However, there was no significant difference between the rotary groups and hand filing group in terms of presence of complete root fracture ($p = 1$) or any root fracture ($p = .076$).

Conclusion

Within the limitations of this study, it was concluded that canal preparation with hand files or rotary files could induce dentinal defects. There was no significant difference between groups in terms of crack formation.

Dedication

"Opportunities to find deeper powers within ourselves come when life seems most challenging"

- Joseph Campbell

This thesis is dedicated to my parents, to my sisters, to my brother and to my little family, for their unconditional love and support, throughout my journey

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List of Abbreviations

RCT	Root Canal Treatment
VRF	Vertical Root Fracture
Micro Ct	Micro computed tomography
CEJ	Cementoenamel Junction
AF	Apical foramen
NiTi	Nickel Titanium
SS	Stainless Steel
mm	Millimeter
ml	Milliliter
g/cm	Gram per cubic centimeter
NaOCl	Sodium Hypochlorite
PDL	Periodontal ligament
M-Wire	Memory wire
HyFlex CM file	HyFlex controlled memory file
rpm	Revolutions per minute
Ncm	Newton centimeters
LED	Light Emitting Diode

Introduction

Complete removal of infected tissues, debris and micro-organisms from the root canal system is the main goal of Root Canal Treatment (RCT). Its purpose is to prepare the root canal space in order to improve the irrigation efficacy as part of chemomechanical preparation. Infiltration and subsequent infection of the root canal system by oral microbial flora is the major etiology of endodontic pathosis.[1] Chemomechanical instrumentation aims to remove microorganisms, remaining pulp tissue, and dentin debris from the root canal system.[2] Moreover, chemomechanical preparation is designed to develop a continuously tapering canal while keeping the apical foramen as small as practical. Many studies using extracted teeth showed that dentinal damage and defects could be induced by some instrumentation methods.[3]

The first commercially obtainable endodontic instruments were brought to the market in 1875. However, instrument design kept changing and improving over time to achieve proper cleaning and shaping and to reduce the percentage of root canal treatment failures.[2,4] In 1915, K-file instruments were produced by the Kerr Company. Since then, K-files are the most commonly used SS hand files in endodontic treatment.[5] However, the rigidity of the Stainless Steel K-files (SS K-file) resulted in straight canals that did not follow the natural path of canals with a curvature >11°. Using SS K-files could affect the prognosis of curved canals.[6] The need for more effective and refined instruments was clearly shown by Hess in 1921. The main purpose to changing the instruments' design was Complex anatomy of root canal system.[7]

In order to limit procedural errors, clinicians and manufacturers adopted a multitude of methods to overcome the unfavorable mechanical properties of SS alloys when negotiating curved canals. The introduction of nickel-titanium (NiTi) instruments offered new methods for root canal preparation with the possibility of avoiding major drawbacks of traditional instruments.[8]

Regardless of the instrument or technique used, unique complex morphology of the root canal system makes mechanical instrumentation one of the most challenging tasks. The apical third is the most difficult area to clean and to preserve the natural canal anatomy because of the inability of the instruments to contact and plane canal walls. This is especially true in cases where root canals are curved and thin where instrumentation can lead to procedural errors. Consequently, instrument designs, alloy properties, and canal curvature are important aspects that determine the possibility of greater apical enlargement in narrow canals to minimize procedural mistakes.[9,10]

There are many procedural errors that can take place during canal instrumentation. Ledges, perforations and instrument separation are some common complications. The least desired complication in root canal treatment is perforation in which an iatrogenic opening through the root is made.[11] Perforations cause chronic inflammation resulting in the formation of granulation tissue with irreversible clinical attachment loss if not repaired with the proper materials.[12]

Canal transportation is another undesirable error during instrumentation in which an altered pathway is created from the original canal. It is one of the most common technical mistakes that occurs during the instrumentation, especially in curved canals. Root canal transportation could affect the root canal cleaning which can lead to persistent apical lesions, or it could weaken the canal walls which could lead to root perforations or vertical root fractures.[13]

Vertical root fracture (VRF) is considered one of the most unfavorable complications in root canal treatment, which may lead to tooth extraction. VRF usually originates from an apical to coronal direction of the root or it can originate from the cervical part of the root and extend apically.[14,15] Walton et al.[16] found that 10% of VRFs were incomplete fractures, which involved only one side of the root; however, 90% were complete fractures which involved two root surfaces. VRF extends to periodontal ligament and the separation between the root segments is increased due to tissue growth into the fracture space which leads to periodontal breakdown followed by the development of a severe osseous defect. Irritants such as food debris, sealer, necrotic tissue, bacteria, and unidentifiable amorphous substances found in canals were contiguous with fracture also.[16]

For VRF confirmation, three types of reference standards have been selected: confirmation during surgical flap procedure which helps to visualize the pattern of bone loss and fracture, confirmation after tooth extraction, and radiographic identification. Although evidence based data concerning the diagnostic accuracy is lacking, the diagnostic process depends on a combination of patient complaints, clinical findings and radiographic evaluations.[17]

Radiographically the 'halo' appearance which is a combination of periapical and perilateral radiolucency.[18] lateral periodontal radiolucency along the side of the root,[19] or angular radiolucency from the crestal bone end along the side of the root [20] are the most common radiographic features of VRF.

The most common clinical signs and symptoms of VRF include a deep osseous defect (deep probing) on the buccal aspect of the susceptible teeth and root.[18] Previous studies found osseous defect in high percentages and with statistical significance: Meister et al.[21] (93%), Tamse[22] (64%), Testori et al.[20] (78%), and Tamse et al.[23] (67%). Another clinical sign of VRF is a sinus tract located close to the gingival margin. This type of sinus tract was found by Tamse et al.[23] in 35% of cases and by Testori et al.[20] in 42% of cases with VRF.

VRFs in endodontically treated teeth have different causes which can be divided into predisposing factors or iatrogenic factors.[18] Loss of healthy tooth structure,[24, 25] the unique anatomy of root canal,[26] loss of tooth moisture in pulpless teeth,[27] a previous crack in the dentin,[28] and loss of alveolar bone support [29] are all recognized as predisposing factors to VRF.[18] However, RCT and the use of intraradicular posts are considered as iatrogenic factors for VRF. Over instrumentation should be avoided especially in roots that are most susceptible to fracture such as the maxillary and mandibular premolars and the mesial roots of the mandibular molars.[17, 29, 30, 31] Adorno et al.[32] found that root canal preparation was strongly associated with crack initiation and propagation at the apical third regardless of the technique used. Moreover, lateral condensation of gutta-percha is considered one of the main causes of VRF. It also could be caused during the restorative procedure that is done after RCT such as over preparation for a post, selection of an inappropriate post and improper positioning of it inside the root canal.[33]

Nickel-Titanium alloy (NiTi) was introduced to endodontics in 1988 by Walia et al.[34] because of its higher flexibility than stainless steel instruments which facilitate RCT. NiTi mechanical properties such as shape memory effect, which is a unique ability to recover their original shape after being deformed through heating, and super elasticity characteristics, which allow them to return to their original shape following significant deformation, make it a very special alloy in endodontics. The NiTi flexibility allows the instruments to follow the original root canal pathway effectively. This unique property of NiTi alloys has made an obvious transformation in the endodontic manufacturing of intracanal instruments, which has improved the speed and efficacy of the root canal treatment.[10, 34, 35]

Although rotary instrumentation requires less time to prepare canals compared with hand instrumentation,[36] hand filing has been reported to produce fewer (or no) dentinal cracks,[37] crack initiation, or propagation.[38] The incidence of root fracture is increased when more tooth structure is removed, and there are not cracks evident until 40%–50% of dentin has been removed.[39] Root fracture could occur due to a micro crack or craze line that originates with frequent stress application by endodontic or restorative procedures and occlusal forces.[37]

A study by Burklein et al.[40] compared root canal preparation with a single-file reciprocating system with sequential full rotational files. It was shown that reciprocating files formed more cracks in the apical third of canals. In another study, Ashwinkumar et al.[41] found that ProTaper Universal rotary file produced more micro-cracks than reciprocating WaveOne or ProTaper hand files, and no micro-cracks with NiTi hand K-files.

A study by Fuss et al.[42] showed a relatively high percentage of VRFs (10.9%) in endodontically treated teeth. Various methods have been used in vitro to detect dentinal defects such as thermography,[43] Micro–Computed tomography (Micro-CT) technology,[44] scanning electron microscope,[41] and visualization of images of the apical surface.[44] The assessment of pictures taken under magnification after root sectioning is the most commonly used methodology to evaluate in vitro the presence of dentinal defects after root canal instrumentation,[3] root canal filling,[44] and root canal retreatment.[45] Moreover, a recent study found that light emitting diode (LED) transillumination enhanced the visualization of dentinal defects in uninstrumented roots.[46]

By comparing hand filing with rotary filing, a study showed that using rotary NiTi files (K3 and ProTaper) caused more dentinal defects (crack and dentinal detachment) compared to hand filing at different levels of instrumentation. However, using rotary files at a level shorter than the apical foramen (AF) reduced the incidence of cracks.[47] Fewer cracks were observed when instrumentation was 1 mm short of the apical foramen, and the use of rotary NiTi (Profile, K3 and EndoWave) was associated with more cracks.[48] Another study showed that there were no significant differences between the hand filing group and rotary (ProTaper) group in regard to dentinal defects. Moreover, they concluded that ProTaper rotary system produced fewer cracks when used according to the manufacturer's instructions.[49]

Several attempts have been made to improve the mechanical properties of NiTi alloy. An innovative process of heat-treating NiTi has changed the transformation behavior of the alloy. By using this thermal processing, it is possible to adjust the transition temperature of the NiTi alloy itself which enhances the flexibility and the cyclical fatigue of the instruments.[50]

In 2007, Dentsply Tulsa Dental produced a new generation of NiTi wire, the M-Wire alloy. Several studies have reported that M-Wire provides more flexibility and resistance to cyclic fatigue as compared to the conventional NiTi instruments.[51, 52] This wire is a mixture of nearly equal amount of R-phase (a third rhombohedral phase when transforming from the austenitic phase to the martensitic phase) and austenite. Vortex Blue (Dentsply, Tulsa, OK) is an example of M-Wire rotary file which has a “blue color” oxide surface layer. Compared with ProFile Vortex M-Wire, the hard titanium oxide surface layer on the Vortex Blue instrument may compensate for the loss of hardness which enhanced the cutting efficiency and wear resistance.

Controlled memory (CM) HyFlex (Coltène Whaledent, Cuyahoga Falls, OH, USA) rotary instrument is another example of new generation NiTi alloy. HyFlex CM files are made with a specific thermal manufacturing procedure that helps control the material's memory and allows pre-bending of files of greater diameter and taper if needed. The manufacturer claimed that due to the super flexibility of HyFlex CM files, they are best suited to prepare curved root canals and possess a superior centering ability compared with conventional NiTi instruments.[50]

K-Flexofile is a hand file made from high-grade stainless steel and twisted triangular cross section to increase its fracture resistance. Due to the higher flexibility and cutting efficiency of non-cutting tip files, they are considered the first choice for curved and narrow canals rather than conventional SS hand files. It has been found that NiTi instruments prepare curved canals in more centric and circular ways than stainless steel files do. However, other studies found the non-cutting tip SS files are superior to NiTi files regarding the enlargement of curved canals.[52]

A study by Liu et al.[47] showed that vertical root fracture and microcrack formation could be seen in root dentin during and after endodontic instrumentation with conventional NiTi files at different working lengths. It is not known what the incidence of microcrack formation in root dentin after root canal preparation with the newer technology of NiTi alloy at different instrumentation lengths is after preparing the apical third of the canal with hand files first.

Aim and Hypothesis

Aim:

The aim of this in-vitro study was to compare the incidence of generation of dentinal defects in the apical third of human extracted teeth after canal preparation with new rotary files (Vortex blue rotary file and HyFlex CM file) at different instrumentation lengths after hand filing to canal preparation with hand filing only (K-Flexofile).

Hypotheses:

- It was hypothesized that preparation using the newer NiTi alloy technology files 2 mm shorter than working length (WL) causes less dentinal fracture than using them to the full working length.
- Hand filing causes the least fracture at working length.
- There are no differences between vortex blue rotary file and HyFlex CM rotary file as rotary systems.

Clinical Significance:

The results of this in vitro study could provide useful information about whether the newer NiTi alloy technology reduces vertical root fracture formation at the apical third.

Materials and Methods

This in vitro study was done on extracted human teeth (N = 120). The sample was divided into 6 groups of 20 teeth each. (See Table 1).

- **Group 1:** Control group (No preparation)
- **Group 2:** Hand file to working length (Stainless steel K- Flexofile)
- **Group 3:** Hand file to working length and Vortex Blue rotary file (Dentsply, Tulsa, OK) to working length.
- **Group 4:** Hand file to working length and Vortex Blue rotary file (Dentsply, Tulsa, OK) to -2 mm of the working length.
- **Group 5:** Hand file to working length and HyFlex CM file (Coltène Whaledent, Cuyahoga Falls, OH, USA) to the working length.
- **Group 6:** Hand file to working length and HyFlex CM file (Coltène Whaledent, Cuyahoga Falls, OH, USA) to -2 mm of the working length.

Block randomization was done, blocking on arch, to ensure that each group had the same proportion of maxillary and mandibular anterior teeth. The “sample” function of R Version 3.4.2 was used to conduct the randomization.

Inclusion criteria:

1. Permanent teeth
2. Anterior teeth with a single straight canal (Vertucci's type I root canal morphology)
3. Anterior teeth with root length between 10 – 16 mm

Exclusion criteria:

1. Cracked or fractured root
2. Teeth with multiple roots
3. Teeth with caries or restorations within 3 mm from cementoenamel junction (CEJ)
4. Teeth with coronal fractures within 3 mm from cementoenamel junction (CEJ)
5. Teeth with curved canals
6. Teeth with calcified canals
7. Teeth with an open apex

The study was carried out using one hundred twenty extracted anterior human teeth (N = 120) which followed the inclusion criteria. The teeth were collected at Tufts University School of Dental Medicine, from the Dr. J. Murray Gavel Center for Restorative Dental Research. Selected teeth were cleaned with ultrasonic scaler (Cavitron GEN-119; DENTSPLY Intl) to remove any debris, and then placed in 5.25% sodium hypochlorite (NaOCl) diluted 1:10 with tap water at room temperature.

Preparation of Samples:

All teeth were examined with a stereomicroscope (Carl Zeiss, Oberkochen, Germany) under 13.6X magnification and radiographs were taken to evaluate for exclusion. The crowns of all teeth were sectioned 3 mm above the cementoenamel junction (CEJ) using an Isomet 1000 Precision saw (Buehler Ltd, Evanston, IL, USA) with water cooling to create straight line access. The working length was determined by inserting a size #10 K-File (Dentsply Maillefer, Switzerland) until the tip of the file was visible at the apical foramen (AF) and subtracting 1 mm from the length under 13.6X magnification.[49]

All roots were wrapped with a single layer of aluminum foil for PDL simulation and embedded in autopolymerizing acrylic resin (Caulk Orthodontic Resin; Dentsply Intl) until set. The “sockets” were then filled with a hydrophilic vinyl polysiloxane impression material (Regisil; Dentsply Caulk, Dentsply International Inc, Milford, DE) using a molding syringe and the teeth were reinserted into the created “sockets”.[39]

Cleaning and Shaping:

All canal apices of all study groups except the control group were prepared with a stainless steel K-Flexofile (Dentsply Maillefer, Ballaigues, Switzerland) up to a master apical file size #30-35 depending on canal anatomy with watch-winding and filing motions. The cervical third of each canal was flared with #2 and #3 Gates-Glidden drills (Dentsply Maillefer, Ballaigues, Switzerland) in a sweeping motion.

Group 1 (N = 20): no preparation was done.

Group 2 (N = 20): the canal was flared using a step-back technique with size # 40 to size # 60 stainless steel K-Flexofile (Dentsply Maillefer, Ballaigues, Switzerland) in 1-mm increments. K- Flexofile # 10 or # 15 was used to recapitulate between each file size. Each canal was irrigated with 10 ml of 5.25% NaOCl between each instrument using a syringe with a 27-gauge needle.

Group 3 (N = 20): Hand filing was done with a stainless steel K-Flexofile (Dentsply Maillefer, Ballaigues, Switzerland) to a size #30-35 then Vortex Blue Rotary File (Dentsply, Tulsa, OK) to the working length in a torque controlled headpiece (Dentsply, Tulsa, OK) was used to the working length (WL). Vortex Blue rotary file was used in a crown down sequence by using: # 35/.06 taper, # 30/.04 taper, # 25/.06 taper and # 25/.04 taper at constant speed at 500 RPM (Revolutions per minute) and 132 g/cm torque to the working length. A smaller file was used if resistance occurred before reaching the working length. Between each rotary file recapitulation with a #10 or #15 K-File was done to maintain glide path to the working length. Each canal was irrigated with 10 ml of 5.25% NaOCl between each instrument using a syringe with a 27-gauge needle.

Group 4 (N = 20): same as Group 3 except Vortex blue rotary file was used to – 2 mm of the working length.[47]

Group 5 (N = 20): Hand filing was done with a stainless steel K-Flexofile (Dentsply Maillefer, Ballaigues, Switzerland) to a size #30-35 and then HyFlex CM file (Coltène Whaledent, Cuyahoga Falls, OH, USA) was used to the working length. HyFlex CM instruments were used in a single length technique with a speed of 500 rpm, and the torque setting of 2.5 Ncm according to the manufacturer's instructions. All instruments were used to the full working length. The instrumentation steps were:

- **Step 1.** Started with the 08/25 file as an orifice opener.
- **Step 2.** Inserted file with 0.04 taper and size #20 to the working length in a pecking motion without pressure. If resistance occurred, a 02/15 hand file to recapitulate was used.
- **Step 3.** Inserted file with 0.04 taper and size #25 to the working length in a pecking motion without pressure. If resistance occurred, a 02/15 hand file to recapitulate was used.
- **Step 4.** Inserted file with 0.06 taper and size # 20 to the working length in a pecking motion without pressure. If resistance occurred, a 02/15 hand file to recapitulate was used.
- **Step 5**. Inserted file with 0.04 taper and size #30 to the working length in a pecking motion without pressure. If resistance occurred, a 02/15 hand file to recapitulate was used.
- **Step 6**. Inserted file with 0.04 taper and size #35 to the working length in a pecking motion without pressure. If resistance occurred, a 02/15 hand file to recapitulate was used.

In Step 1, if the working length was reached in large canals, it was possible to go directly to Step 4. Once the instrument was negotiated to the end of the canal and had rotated freely, it was removed. Each canal was irrigated with 5.25% NaOCl between each instrument using a syringe with a 27-gauge needle. A total of 10 ml of NaOCl was used for each canal.

Group 6 (N = 20): Same as group 5 except the HyFlex CM rotary file was used to – 2 mm to the working length.

In all experimental groups, RC-Prep (Premier Dental Company) was used as lubricant during instrumentation.

Sectioning and Microscopic Examination of the Root:

All roots were sectioned horizontally at 2 mm from the apex with an Isomet 1000 Precision saw (Buehler Ltd, Evanston, IL, USA) under water coolant.[3] Slices were observed under a stereomicroscope (Carl Zeiss, Oberkochen, Germany) using a cold light source (KL 2500 LCD; Carl Zeiss). Pictures were taken with a digital camera (Canon 6D) attached to a stereomicroscope under 13.6X magnification. The dentin was inspected and defects were noted**.** The samples were initially evaluated by three examiners: first and second year postgraduate endodontic residents who were not involved in the specimen preparation. The dentinal defects were categorized according to the Wilcox et al. classification:[39]

1. **No defect:** defined as root dentine devoid of any line or crack either at the external surface of the root or at the internal surface of the root canal wall**.**
2. **Complete fracture:** defined as a line extending from the root canal space to the outer surface of the root.
3. **Incomplete fracture:** defined as all other lines observed that did not extend from the root canal to the outer root surface such as craze lines which extend from the outer surface into the dentin but do not reach the canal lumen or a partial crack which extend from the canal wall but do not reach the external surface of the root.

After the data were obtained according to the Wilcox et al. classification, they were converted to two binary variables. The first variable indicated the presence or absence of complete fracture (the “no defect” and “incomplete fracture” categories were both considered as absence of complete fracture). The second variable indicated the presence or absence of any fracture (the “complete fracture” and “incomplete fracture” categories were both considered as presence of any fracture). For each of these two new variables, the kappa statistic was computed for each pair of examiners, all of whom were blinded to the sample’s group. If any kappa value was below 0.40 (indicating less than moderate agreement according to Landis and Koch)[53], the evaluation process was repeated with new examiners (again, first and second year postgraduate endodontic residents who were not involved in the specimen preparation and were blinded to the sample’s group). The first two sets of examiners both exhibited at least one instance of a kappa value below 0.40. Therefore, a third set of examiners was chosen. Prior to evaluation by this third set of examiners, a calibration lecture was given to them by the master resident including photos of other teeth, images of other studies, and a quiz to verify their understanding. In the evaluation of the study samples, the third set of examiners all exhibited kappa values between 0.559 and 0.684 (see the Results section for details), indicating moderate or substantial agreement according to Landis and Koch. Therefore, the results of the third set of examiners were used in the final statistical analysis. In instances where not all three examiners agreed, the final classification was based on the findings of the majority of the third set of examiners.

Power Calculation:

The statistical software R (Version 3.3.1) was used to conduct a power calculation. Based on the fracture rates obtained by Liu et al.[47], a sample size of N = 20 per group achieved a Type I error rate of 5% and power exceeding 99%.

Statistical Analysis

Counts and percentages were calculated. Statistical significance was determined by Fisher's exact test. SPSS version 24 was used in the analysis. Statistical significance was set at $p < 0.05$.

Cohen's Kappa coefficient was used to measure the inter-examiner reliability. According to Landis and Koch's guidelines, values below 0 indicate no agreement. Additionally, values between 0 and 0.20 indicate slight agreement and fair agreement is indicated for values between 0.21 and 0.40. Moreover, values between 0.41 and 0.60 are considered as moderate agreement, values between 0.61 and 0.80 as substantial and values between 0.81 and 1 as almost perfect agreement.[53]

Results

Counts and percentages of complete root fracture by group and counts and percentages of any root fracture by group are presented in Table 2 and Table 3 respectively.

The control group (Group 1) showed no defects. Complete root fracture was only observed in 1 of 20 teeth (5%) of Group 3 and Group 6. There was no statistically significant difference between groups (p = 1).

When considering any root fracture, 6 of 20 teeth (30%) of Group 3 showed any root fracture. Although only 1 of 20 teeth (5%) of Group 2 and 2 of 20 teeth (10%) of Groups 4, 5, and 6 exhibited any root fracture, there was no statistically significant difference between groups (p = .076).

For the third set of examiners, Cohen's Kappa indicated moderate agreement in the case of complete root fracture between rater 1 and rater 2 and between rater 2 and rater 3 (.559), and it showed substantial agreement between rater 1 and rater 3 (0.658). In the case of any root fracture, the agreement between rater 1 and rater 2 (.614), rater 1 and rater 3 (.684), and rater 2 and rater 3 (.619) was substantial (Table 4).

Discussion

The primary goal of chemomechanical root canal preparation is to maintain the original shape of the canal and to eliminate the bacteria from the entire root canal system. However, RCT can result in development of dentinal cracks which can lead to vertical root fractures.[2, 3] Different nickel-titanium (NiTi) instruments with different designs have been developed, and their use has been linked to dentinal defect creation such as incomplete cracks or even vertical root fractures.[3, 47] The aim of rotary endodontics is to reduce the treatment time and increase efficiency and accuracy of root canal preparation. Root canal treatment with different rotary NiTi files may cause stress and strain which can lead to microcrack or craze line formation in root dentin.[54] Root canal procedures produce stresses that can possibly initiate and propagate cracks from within the root canal in the apical region.[32]

VRF is a serious complication during root canal treatment which jeopardizes the prognosis of many cases that end up with extraction. A study showed that VRFs related to RCT were found in 3.69% of endodontically treated teeth.[55] VRFs may originate from stress concentration arising from mechanical preparation. Various instrumentation techniques and systems which have different cutting blades, tip designs and tapers produce lateral forces which could end up with different types and degrees of dentinal damage to the root canal wall.[3, 32, 48, 56, 57] Wilcox et al.[39] concluded that the more root dentin is removed, the more likely a root is to fracture.

In the present study, the dentinal defect propagation was evaluated at the apical one third after using heat treated NiTi files (Vortex blue and HyFlex CM) and hand K-Flexofile at different instrumentation lengths on extracted anterior human teeth. No defects were found in the control group. Considering complete root fracture, the study showed that only Group 3 (vortex blue to WL) and Group 6 (HyFlex-CM to WL) had 5.0% complete root fracture (Table 2). However, when considering any root fracture, Group 3 showed more dentinal defects (30%) than the other groups but the difference was not statistically significant (Table 3). According to Liu et al.[47] no cracks were created when instrumentation ended at –2 mm of WL, probably because sharp apical curvatures were found within the apical 2 mm.

A study showed that instrumentation length had a substantial effect on propagation of apical cracks with rotary NiTi files. The level of file insertion played a major role in cracks originating in the root canal. When the working length terminated at the apical foramen, there was a higher possibility of formation of cracks as a result of wedging force of the file.[58] Results of the present study confirmed previous studies' results: regardless of the techniques used, root canal preparation can possibly create dentinal cracks on the apical root canal wall as well as the apical surface. Moreover, it has previously been found that fewer cracks might be produced in the apical one third when root canal preparation terminated -1 mm short of the apical foramen.[3, 32, 48] Also, this study is in agreement with other studies that have found there was no statistically significant difference between hand files and rotary files in terms of crack formation although other studies used rigid stainless steel hand files.[32, 58, 59]

Vortex Blue and HyFlex CM rotary NiTi instruments are manufactured using a novel heat treatment which enhanced its flexibility.[51, 52] The percentages of dentinal cracks that formed after using Vortex Blue and HyFlex CM rotary instruments were lower than other studies which used conventional rotary NiTi files.[32, 57, 58, 59] This might be related to their heat treatment structure which gives the files extra flexibility. Previous studies [60, 61] showed that these instruments have fewer dentinal defects compared with traditional NiTi rotary instruments which is in agreement with the current study.

Although some studies reported that no dentinal cracks were seen in teeth instrumented with flexible SS hand files and there was a significant difference in amount of cracks formed with rotary NiTi files and hand files,[3, 37, 47, 56, 62] the current study found that there was no significant difference between the hand K-Flexofile group and heat treated NiTi files groups. However, other studies used premolars and molars to evaluate and compare the incidence of dentinal cracks formation caused by rotary NiTi and flexible SS hand files at different working lengths. In this study, both mandibular and maxillary anterior teeth were used; it has previously been claimed that lower anterior teeth are probably more susceptible to forces during instrumentation due to their smaller sizes and thinner dentinal walls.[49]

In this study, instrumentation with flexible hand files created less dentinal damage to the root canal wall. This could be credited to the less damaging movements of the hand files in the root canal compared with engine operated files and less taper (0.02) compared to rotary NiTi instruments.[37, 56] However, there was no statistically significant difference between groups; therefore, the observed difference could be due to random variation. Liu et al.[47] recommended that canal instrumentation with rotary files should be ended -2 mm short of AF to avoid cracks formation, whereas the apical 2 mm should be instrumented with flexible hand files only. Although this study found a non-zero percentage of incomplete root fracture in the hand file group, the percentage was only 5%. Therefore, the results support Liu et al.'s recommendation.

The sectioning technique used in the present study allowed the evaluation of the effect of root canal preparation on the root dentin by direct examination of the root canal wall to determine whether there was complete root fracture or incomplete root fracture. Nevertheless, the sectioning method is destructive; this might be a limitation of the current study.[3] A study showed that micro-CT imaging is more accurate and less destructive than stereomicroscopy and many slices can be analyzed per tooth without producing defects. Moreover, the authors stated that only a few slices per tooth could be evaluated by the sectioning technique and there is a higher chance of missing several defects.[63] However, no dentinal cracks were observed in the control group in the current study. The observed cracks were possibly due to the root canal preparation and not sectioning.

Although we have used maxillary and mandibular anterior teeth which were distributed equally in all groups using stratification, there could still be differences in dentin thickness. This thickness variation could cause significant differences in strength and response to stresses during root canal preparation.

A recent study has claimed that with the aid of light-emitting diode (LED) transillumination, uninstrumented roots might expose dentinal defects that could not be visualized through the classic sectioning methodology.[46] Therefore, further investigations using the a larger sample size of the same type of teeth in all groups and using the micro-CT scanning method with the aid of LED is recommended. Also, using teeth with curved canals may be beneficial.

Conclusions

Within the limitations of this in vitro study, the following conclusions can be drawn:

- All experimental groups showed microcrack formations at 2 mm from the apex.
- Although Vortex Blue files showed more dentinal defects at 0 mm from WL than other experimental groups, there was no statistically significant difference between the experimental groups.
- Using flexible hand file (K-Flexofile) caused fewer cracks in the apical one third, but differences were insignificant.
- Future studies using advanced evaluation technologies and teeth with curved root canals are recommended.

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Appendices

Appendix A: Tables 1-4

Appendix B: Figures 1-6

Appendix A: Tables

Table 1: **Summary of study groups' instrumentation**

Group	Hand File	Rotary File
1	No instrumentation	No Instrumentation
2	K Flexofile # 30-35 to WL	No Rotary Filing
3	K Flexofile # 30-35 to WL	Vortex Rotary File to WL
4	K Flexofile # 30-35 to WL	Vortex Rotary File – 2 mm from WL
5	K Flexofile # 30-35 to WL	HyFlex Rotary File to WL
6	K Flexofile # 30-35 to WL	HyFlex Rotary File to – 2 mm from WL

Table 2: Count and percentage of complete root fracture by group

Group	Count and percentage of absence of complete root fracture	Count and percentage of presence of complete root fracture
1	20 (100%)	0 (0%)
2	20 (100%)	0 (0%)
3	19 (95%)	1 (5%)
4	20 (100%)	0 (0%)
5	20 (100%)	0 (0%)
6	19 (95%)	1 (5%)

Table 3: Count and percentage of any root fracture by group

Group	Count and percentage of absence of any root fracture	Count and percentage of presence of any root fracture
1	20 (100%)	0 (0%)
2	19 (95%)	1 (5%)
3	14 (70%)	6 (30%)
4	18 (90%)	2 (10%)
5	18 (90%)	2 (10%)
6	18 (90%)	2 (10%)

Table 4: Cohen's Kappa coefficient

Examiners	Complete root fracture	Any root fracture
1 vs 2	.559	.614
1 vs 3	.658	.684
2 vs 3	.559	.619

Appendix B: Figures

Figure 1: Isomet 1000 (Buehler Ltd)

Figure 2: All roots were wrapped in a single layer of aluminum foil

Figure 3: All teeth were embedded in autopolymerizing acrylic resin until set

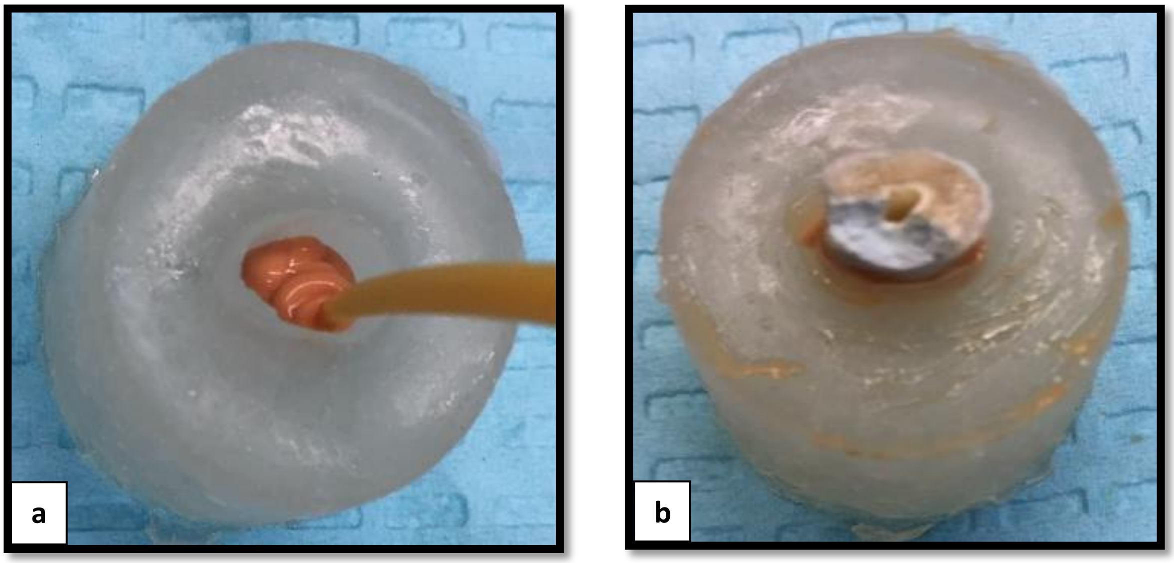

Figure 4: a) The "sockets" were filled with a hydrophilic vinyl polysiloxane impression material
b) The teeth were reinserted into the created "sockets"

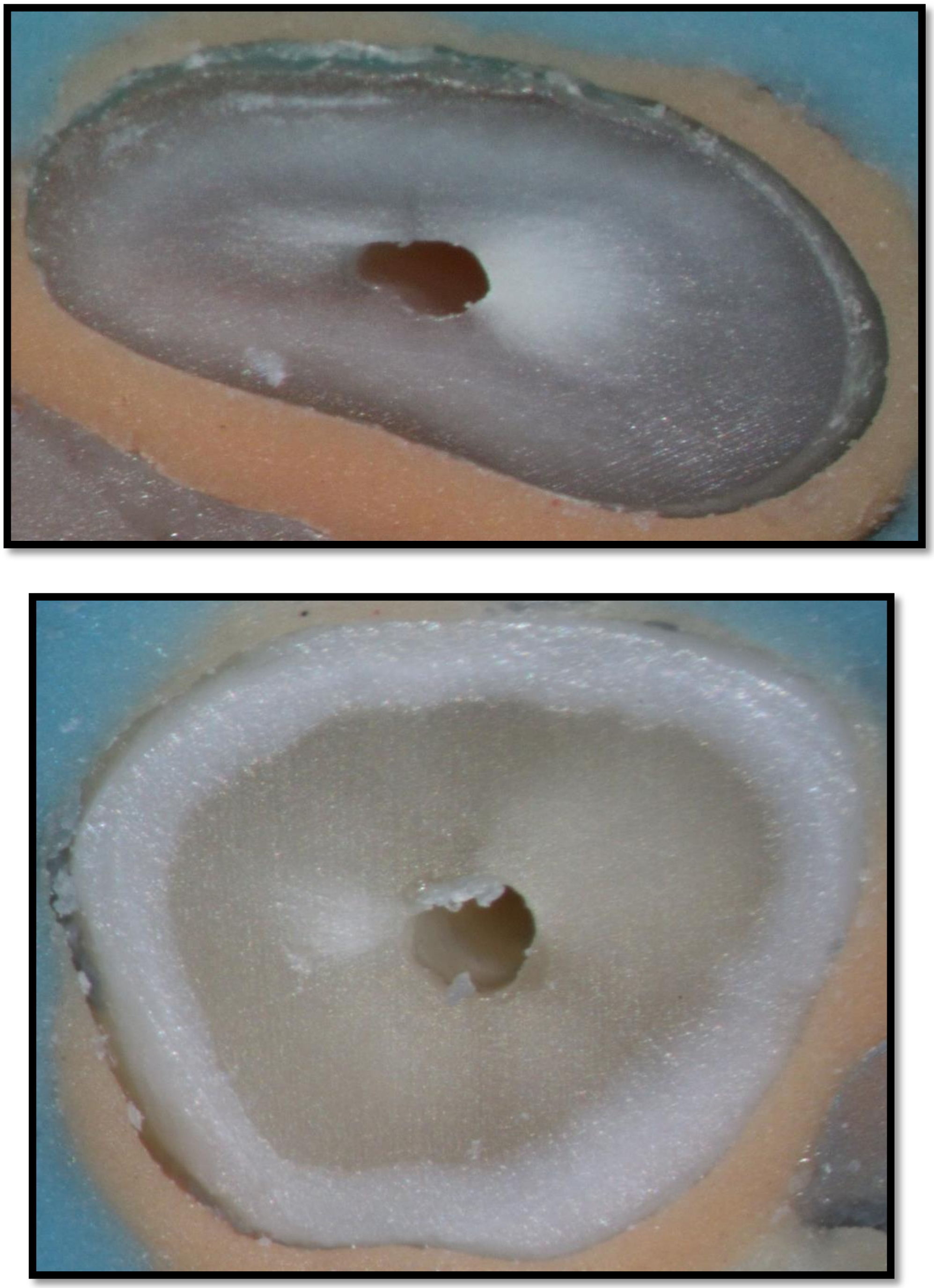

Figure 5: Microscopic images showing no defects at 2 mm level

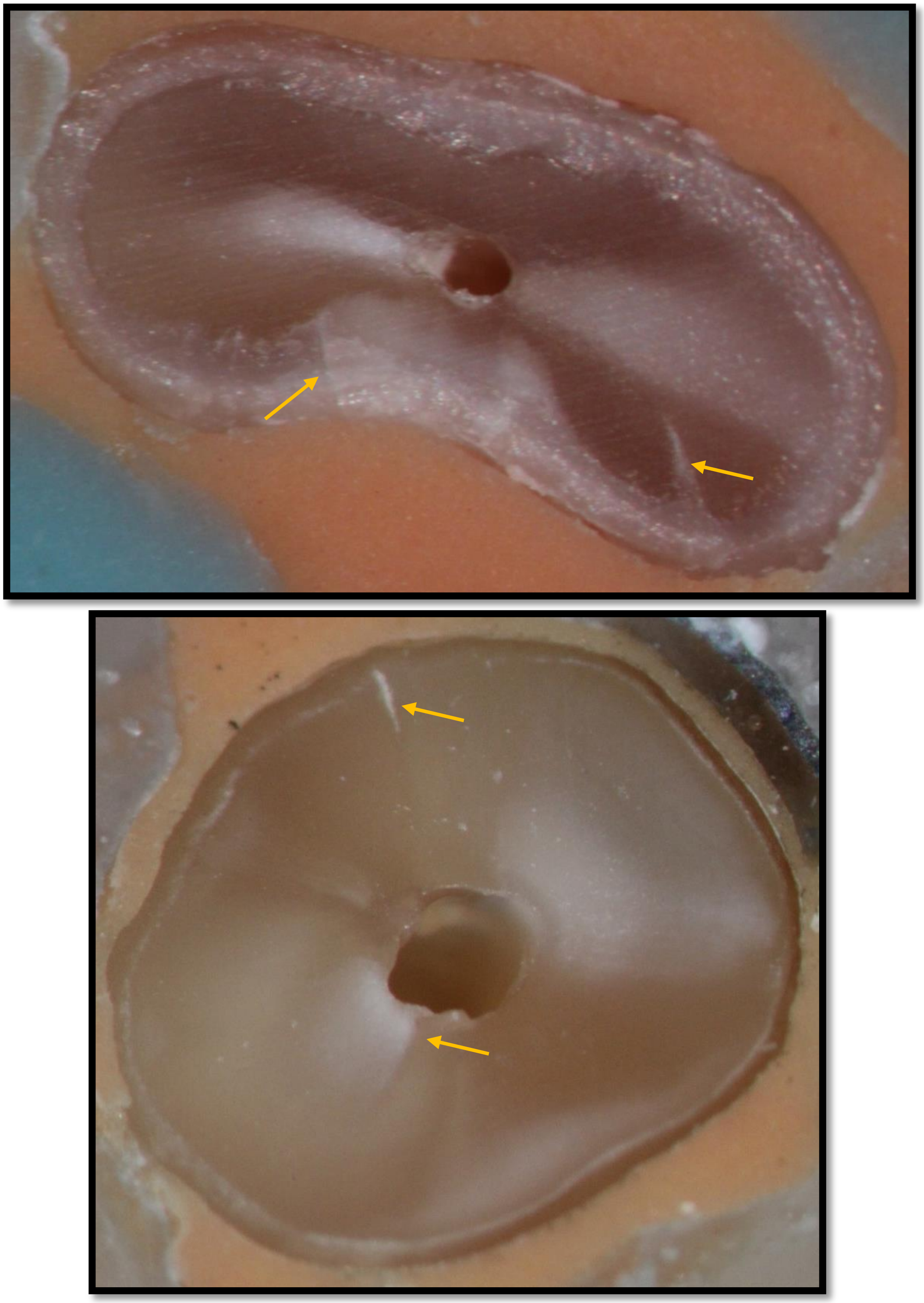

Figure 6: Microscopic images showing incomplete fracture at 2 mm level

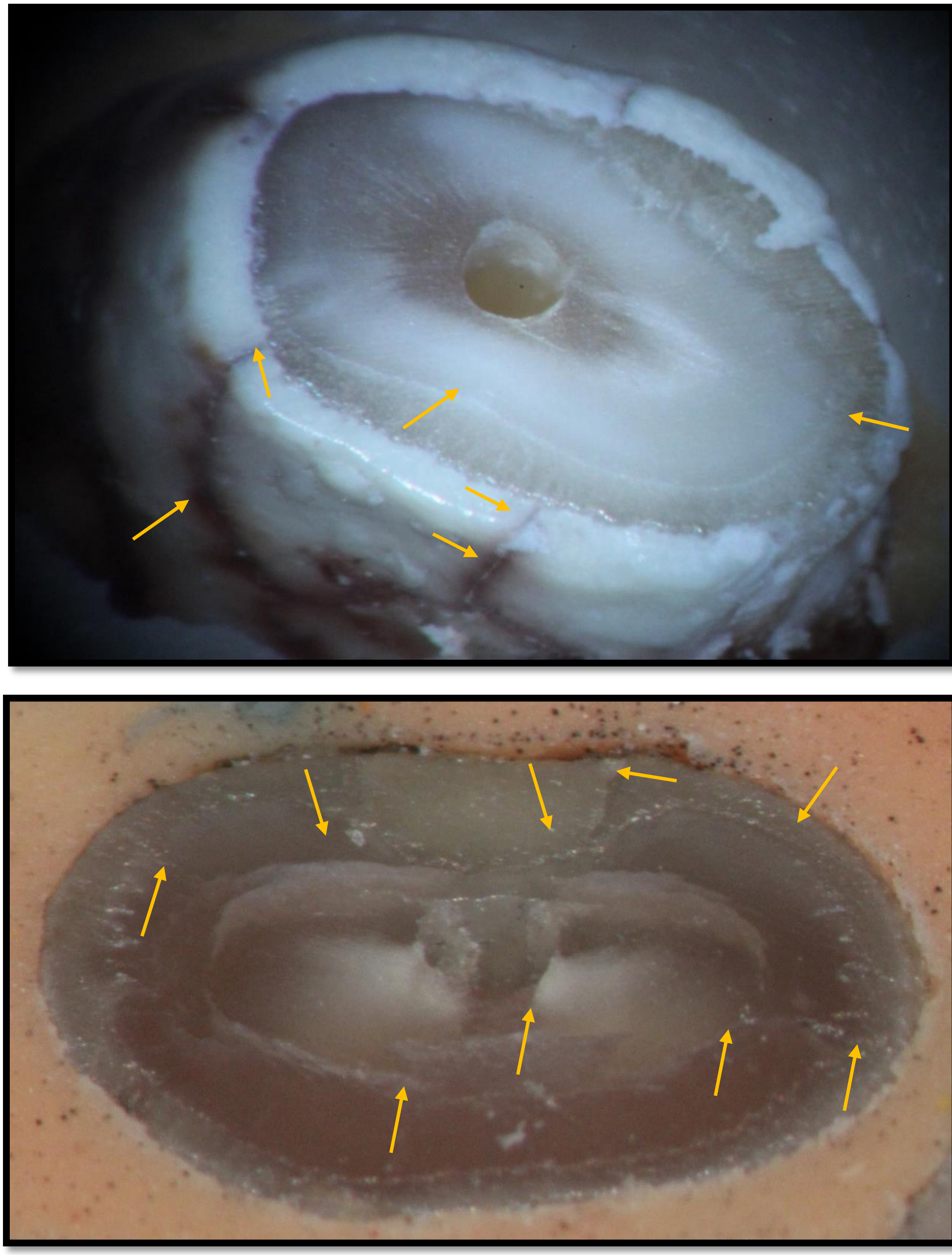

Figure 7: Microscopic images showing complete fracture at 2 mm level