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## **I. Introduction**

Cracks or fractures in teeth became one of major chief complaints by patients in clinical settings. There are symptoms such as sharp pain to the cold or biting force. Despite dentistry has evolved with high technology-based diagnosis and treatments, crack tooth is still addressed as one of the hard-to-diagnose problem by the dentists. This is because crack is not always visible to the clinician and the appearance of the tooth may look sound. In addition, as it is becoming an aged society with increased life expectancy, crack teeth occurrence is becoming more prevalence as people obtain and use their teeth for the longer years. Using teeth for longer years can cause higher risk of tooth fracture.

Because tooth has its own complicated parts, there are different types of the crack teeth depending on the direction, size and location on the tooth. For example, crack line on the crown should be addressed differently from the fracture occurred in the roots. However, for many years, clinicians have been using unclear terms describing tooth crack, causing confusion to both dental team and patients. To clarify the confusion and help communication among the dentists and patients, several attempts were made to unify the definitions, terminologies and classifications (Cameron *et al.*, 1964; Cohen *et al.*, 2003;

Fuss *et al.*, 2001; Krell *et al.*, 2007; Lusting *et al.*, 2000; Opdam *et al.*; 2008). Finally, in 1993, AAE defined five different types of tooth fracture in their article “Cracking the Cracked Tooth Code” to resolve the confusion. These types include craze lines, fractured cusp, cracked tooth, split tooth, and vertical root fracture. Craze lines appear limited to the enamel. If the crack initiates from the occlusal surface and extends downward to pulpal direction, it is called fractured cusps, cracked teeth and split teeth with increased severity. On the other hand, crack can start from the root and it is called vertical root fracture. According to AAE, all crack types except craze line occur most often in the posterior teeth (AAE, 1997; AAE, 2008).

Cracked tooth should be properly distinguished from other categories of the cracks types, which are craze lines, split tooth, fractured cusp and vertical root fracture, because each category should follow different treatment plan. Prior to the research, it is important to make the definition of the terms. In this paper, crack teeth is defined as tooth with an incomplete fracture existing from the crown to subgingival level in mesiodistal direction. The crack line can be found in the tooth crown or crown to the proximal root (Krell *et al.*, 2007, Banerji *et al.*, 2010; Opdam, *et al.*, 2003; Roh *et al.*, 2006; Ricucci *et al.*, 2015; Kim *et al.*, 2013). A vertical root fracture (VRF) on the other hand, is a complete or incomplete fracture initiate from root to the crown direction. The VRF can

include one proximal (buccal or lingual) surface or both surfaces. (Coehn *et al.*, 2006; Schwarz *et al.*, 2012; Sugaya *et al.*, 2015, Chan *et al.*, 1999). The factors associated with different types of tooth fracture of AAE category was previously reported. In this research, it was found that 94.4% of all longitudinal fractured teeth were diagnosed as cracked tooth and VRF. Among them, cracked tooth patients were 81.3%, and the rest 13.1% were diagnosed as VRF (Seo *et al.*, 2012). These high occurrences of cracked tooth and VRF suggested necessity of research on their association factors. Not only the high occurrence, but also, the fact that the treatment plan of the two fracture type leads to completely different result indicated the importance of comparing their causing factors.

In clinical settings, cracked tooth and VRF should be well distinguished because each requires different treatment plan. For example, the treatment planning of cracked tooth can followed by proper root canal treatment. Less severe cracked tooth can be treated with band or temporary crown to reduce the risk of growth of the crack. For the VRF, extraction of that tooth is the only treatment as now. In case of the multi-rooted tooth, removal of the fractured root could be performed by root hemisection, but other conservative treatment has not yet been developed yet (AAE, 2003). Correct diagnosis based on evidence-based reasons can bring beneficial treatment plan for both patients and

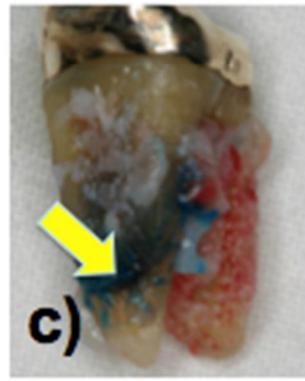
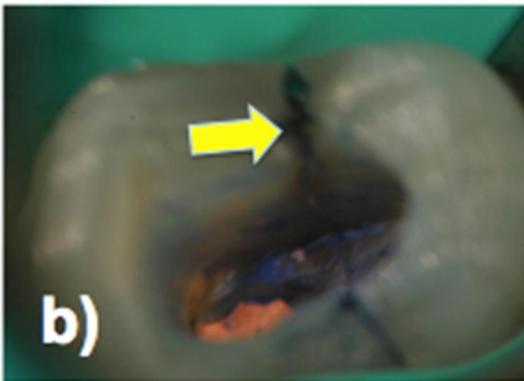
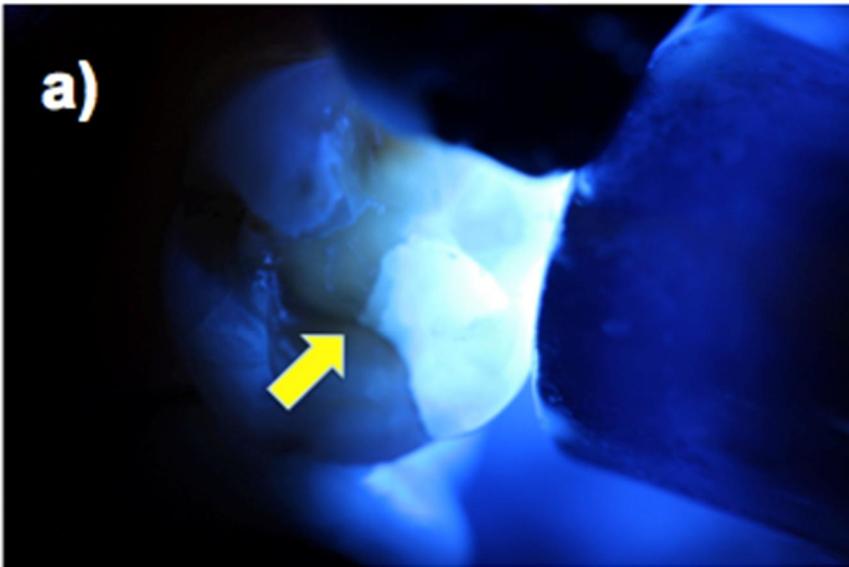
dentist. Despite this demand, the predisposing factors associated with cracked tooth and VRF, such as number of tooth, type of restoration, age or sex is still not yet clearly discovered.

Therefore, the purpose of this study was to compare the factors associated with cracked teeth and VRF provide evidence based understanding and information for better diagnose and prevention. Quick and correct diagnose can bring higher chances of saving the fractured tooth.

## **II. Materials and Methods**

### **Patients diagnosis**

This research was approved by the Institutional Review Board of Seoul National University Dental Hospital (approved number: CRI11016). All patients were given with consent about the research process prior to the diagnosis and treatment. From Jun 2011 to April 2013, patients who visited the Department of Conservative Dentistry in Seoul National University Dental Hospital with chief complaints of unexplainable biting pain, visible crack or suspects were examined. All patients were examined and evaluated by a single clinician to reduce the bias. The procedure of reproducing the symptoms was similar to that of the previous study (Seo *et al.*, 2012). To make biting force, tooth Slooth (Professional Result, Inc, Laguna Niguel, CA), a roll of rubber or a cotton roll was used for the biting test. Ice stick was used to evaluate tooth hypersensitivity to cold. In addition, naked eye examination, transillumination, dye staining, microscope observation, and diagnostic surgery were also utilized to diagnose the tooth fracture. Additional X-rays such as panorama and intra-oral periapical x-rays were also used. Some of these diagnostic tools are illustrated with pictures in Fig.1.



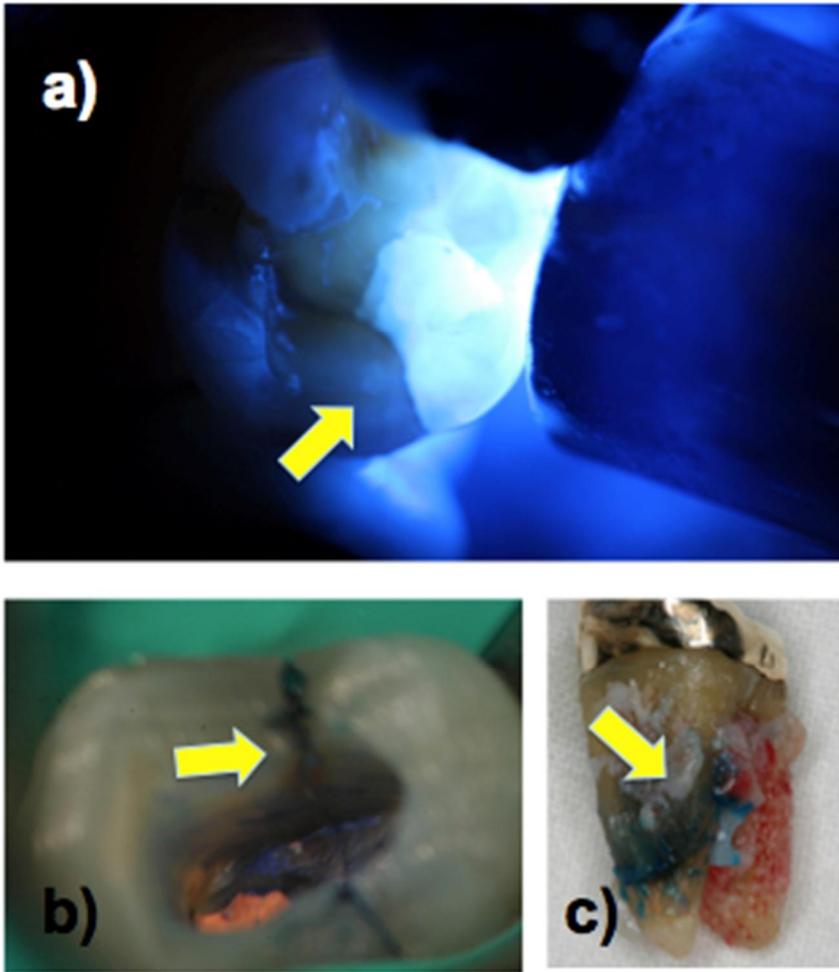


Fig.1 Detecting crack tooth using transillumination light is shown in (a). Dye staining method is also showing the fractured line in crown and root in (b) and (c).

### **Factors recording**

Once patient was classified to have longitudinal tooth fracture, patients' signs, symptoms, age, sex, position and type of the tooth were recorded as well as ice, thermal, EPT test, mobility, previous root canal treatment, restorative material, its width, cavity classification, location of crack, buccal-lingual and/or mesial-distal direction of crack and treatment. Then, these identified teeth were categorized according to the AAE definition of longitudinal tooth fractures: craze line, fractured cusp, cracked tooth, split tooth, and VRF (AAE, 2008).

### **Tooth Crack Selection**

Total 211 cracked teeth were diagnosed. Among them, 171 cracked teeth and vertical root fracture sample were selected for this study. Out of 171, 146 were cracked teeth and 26 were VRFs.

### **Statistical Analysis**

For the statistical R statistical language (R Foundation for Statistical Computing, Vienna, Austria) was used to evaluate the results. Every category of association factors were analyzed. The association between categorical variables was compared using the Fisher exact test. Only factors with significance were listed in this research. A P value  $<0.05$  was considered to be statistically significant.

### **III. Results**

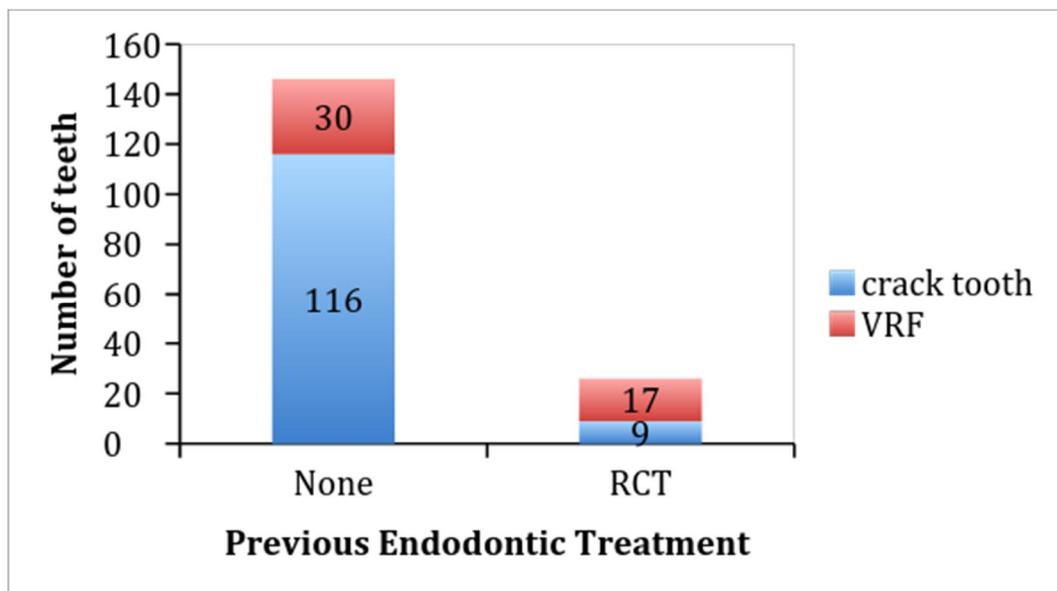
As shown in the table 1, cracked tooth and vertical root fracture did not show significance difference in sex, age, position of tooth, and type of tooth. Cracked tooth occurred mostly in maxillary and mandibular molars than premolars in patients with age of 50-59 years old. VRF occurred more often in first molars. Among various factors associated with cracked tooth and VRF, restoration materials, restoration width, cavity classification, and previous root canal treatment were significantly related in prevalence of occurrence between cracked tooth and VRF. The total of 125 teeth were treated with amalgam filling (16.9%), gold restoration (37.2%), resin and ceramic restoration (15.7%), or were not treated at all (30.2%). Probability of cracked tooth was higher in tooth with no restoration, amalgam, and gold restoration compared to VRF. On the other hand, probability of cracked tooth was lower in resin and ceramic restoration (Fig.2). According to the restoration size and cavity classification at the time of examination, cracked tooth is clearly more prevalent in tooth with class I and class II restorations. Also, tooth with restoration width greater than 1/3 of the occlusal table showed higher cracked tooth probability compared to VRF.

**Table 1.** Number of Cracked Tooth and VRF According to the Sex and Position of the Teeth

Type of fracture	Cracked tooth	Vertical Root Fracture	Total, n (%)	Fisher exact test significance
<b>Sex</b>				
Female	69	14	83	<i>P</i> = 0.670
Male	77	12	89	
<b>Position of tooth</b>				
Premolar	14	3	17	<i>P</i> = 0.342
First molar	65	15	80	
Second molar	67	8	75	

In figure 2, the relationship between fracture type and previously treated tooth with root canal treatment (RCT) is shown. Figure 2 showed that cracked tooth occurred mostly in tooth with no previous root canal treatment (116/125, 92.8 %), whereas VRF occurred easily in root canal treated tooth (30/47, 63.8 %). Teeth with no root canal treatment were significantly related to age in occurring cracks, and probability of cracked tooth compared to VRF increased with age. However, previous root canal treated teeth were not related to age in occurring cracks (Fig. 3).

**Figure 2.** Occurrence of cracked tooth and vertical root fracture (VRF) according to previous root canal treatment.

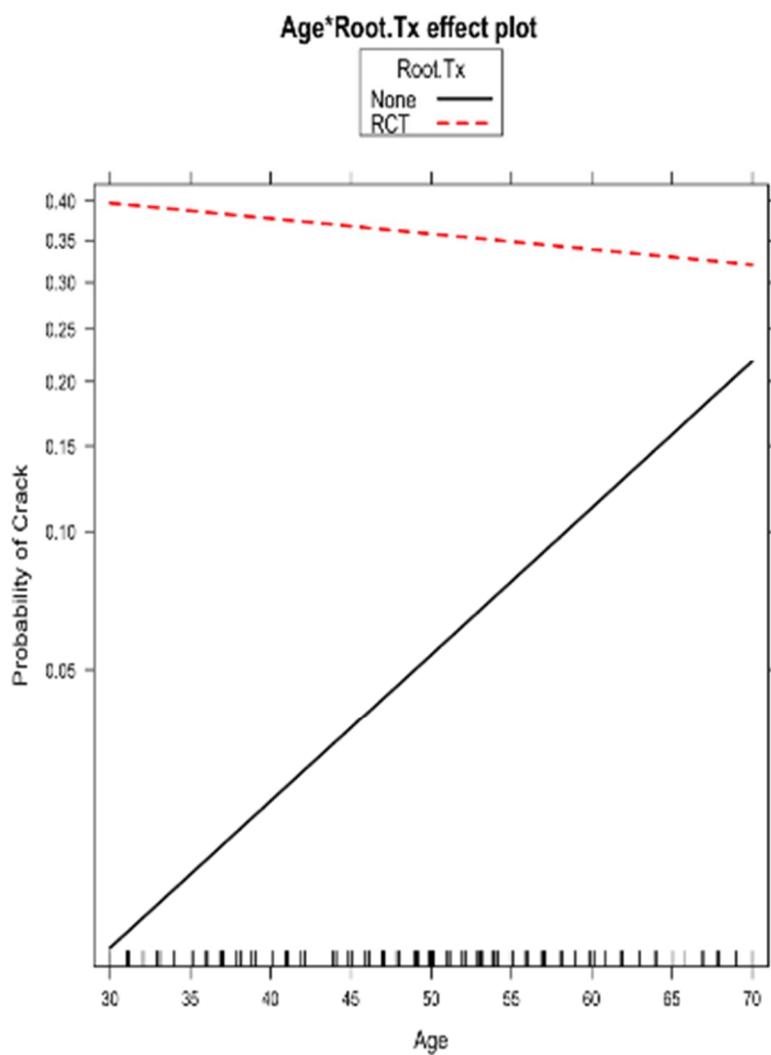


**Table 2.** Association Between Various Factors and Two Most Common Longitudinal Fractures of AAE Categories

	AAE category		Total
	Cracked tooth	VRF	
<b>Direction</b>			
BL	14	14	28
MD	61	9	70
Both	34	3	37
<b>Design</b>			
None	46	6	52
Class I	58	5	63
Class II	20	2	22
Crown	22	13	35
<b>Restoration material</b>			
Amalgam	27	2	29
Gold	55	9	64
Others	18	9	27

<b>Size of Restoration</b>	Cracked tooth	VRF
None	46	7
<1/3	14	2
1/3~2/3	37	3
>2/3	28	2
Crown	21	12

**Figure 3.** Probability of cracked tooth compared to vertical root fracture according to combined effect of age and root canal treatment.



It was reported that crack occurs more in mesial-distal direction while root fracture occurs in buccal lingual but there has been no clinical evidence. As shown in table 2, our result disproves it. Cracked tooth and root fracture happen in bucco-lingual, mesio-distal or both directions in similar manner.

Among the 4 groups of restoration design, that are none (or natural), class I, class II and crown, class I and class II showed higher frequency of cracked teeth than the VRF (Table2). Cracked tooth was found 12 times more common than VRF in class I type restoration and 10 times more common in class II. Crack is clearly more prevalent in class I and II compared to VRF.

Our concern moved on to the restoration material. Crack was more common in amalgam. Gold restoration also showed most crack and root fracture, but, amalgam shows nearly 15 more times of crack tooth than root fracture.

There is a statistical evaluation for restoration material (amalgam, gold, others) with type of restoration (class I, II, crown), but since it is common to apply amalgam for class I treatment, gold inlay for class II treatment and gold for crown restoration, the data did not show much significance.

## **IV. Discussion**

Cracked tooth and VRF are difficult to detect and yet they represent a large proportion of longitudinal tooth fractures. As a result, these have been a major problem addressed by both patients and dentists. In addition, it is becoming an aged society, occurrence of cracked tooth and VRF will be increased as people use their teeth for the longer years, giving it more stress. Therefore, it is important to evaluate the characteristics of cracked tooth and VRF.

In this study, there was no significant difference in sex, age, position of tooth, and type of tooth in prevalence between cracked tooth and VRF (Table 1). The majority of the cracked teeth were reported in the age of 50-59. This is similar to other studies conducted for the Korean population (Roh *et al.*, 2006; Kim *et al.*, 2013; Seo *et al.*, 2012). The resistance of human dentin is known to decrease under fatigue stress with both aging and dehydration (Bajaj *et al.*, 2006). As in previous studies (Chan *et al.*, 1999; Chan *et al.*, 1998; Meister *et al.*, 1980), most of the VRFs were reported in patients 30-69 years of age.

Regarding the position of tooth, the most frequently involved teeth were first molars (46.5%) and second molars (43.5%). Cracked tooth was found similar prevalence between first molars and second molars, whereas VRF was

found high prevalence in first molars. Previous research reported that cracked teeth were most prevalent in mandibular molars (Geurtsen *et al.*, 1992; Hiatt *et al.*, 1973). This was explained due to the wedging effect of the prominent mesio-palatal cusp of the maxillary first molar (Geurtsen *et al.*, 1992; Lubisich *et al.*, 2010; Ehrmann *et al.*, 1990). It is also well known that the incidence of VRF was higher in mandibular first molars and maxillary premolars, because fractures occurred more often in thin, flat roots with smaller mesio-distal diameters (Chan *et al.*, 1999; Yoshino *et al.*, 2014; Llana *et al.*, 2001). In finite element analysis, teeth with oval roots and/or oval root canals have the highest incidence of VRF (Tarnse A *et al.*, 1006; Lertchirakam *et al.*, 2003). In this study, there was no statistical difference in prevalence of cracked tooth and VRF between maxillary and mandibular teeth, agreeing with previous Korean studies (Kim *et al.*, 2013; Seo *et al.*, 2012).

The dental history of a patient has close relationship to the prevalence of fracture of the tooth. Cracks occur in restored teeth, with a direct relationship to the size of the restoration, and there is a higher incidence of cracks in teeth with restored marginal ridges (Cameron *et al.*; 1976; Homewood *et al.*, 1998). However, intact or minimally restored teeth can also be compromised by incomplete fractures, with some studies finding an increased incidence of the syndrome in healthy teeth (Roh *et al.*, 20016; Seo *et al.*, 2012; Ehrmann *et al.*,

1990; Geurtsen *et al.*; 2003; Udoye *et al.*, 2009). In this study, the natural teeth, which had never received any treatments, had higher incidence of cracked tooth compared to the VRF. The same result was observed in amalgam and gold restoration. However, different result was found in resin and ceramic restoration, in which probability of cracked tooth was lower. Previous research has suggested that microcracks form as a result of cusp flexure caused by occlusal load stress during mastication and repeated thermal expansion of the restorative materials (Seo *et al.*, 2012). In contrast, occlusal stress can be distributed through the bonding layer in a bonded type restoration and prevalence of cracks can be reduced (Opdam *et al.*, 2008; Opdam, 2003; Ausiello *et al.*, 2002). Roh and Lee (Roh *et al.*, 2006) studied 154 cases of teeth with cracks and found those not only occur with large or poor restorations, but also with intact teeth as well. Therefore, the possibility of an unrestored cracked tooth should be considered, regardless of the location of the tooth or the presence and size of a restoration. Teeth with deep cusp and steep fossa are more vulnerable to the fracture due to the wedge effect from antagonist cusp, resulting in compressive forces in the cusp and tension forces in the pit. This wedge effect has been suggested as a major cause of broken intact teeth (Geurtsen *et al.*, 1992; Hiatt *et al.*, 1973; Cameron *et al.*, 1976). In this study, teeth with previous root canal treatment showed higher probability of getting VRF (Fig. 2). VRF was easily

developed in endodontically treated tooth than non-endodontically treated tooth according to previous studies (Fuss *et al.*, 2001). Wilcox *et al.* suggested that VRF starts when the root canal has been widened by 40% of the total root width or more (Wilcox *et al.*, 1997). It indicated that the more tooth structure removed, the more likely a root is to fracture. Therefore, clinician should be careful not to enlarge excessively during root canal treatment. We also found that the probability of cracked tooth compared to VRF in non-endodontically treated teeth increased with age, and probability of cracks with endodontically treated teeth was not related with age (Fig. 3). This suggests that, the occurrence of cracks increased with age because of a loss of dentin elasticity in non-endodontically treated teet (Bajaj *et al.*, 2006; Udoye *et al.*; 2009, Rosen *et al.*, 1982). On the other hand, root canal treatment and post insertion could result in significant loss and weakening of tooth structure. This could increase the risk in younger patients. Therefore, the probability of cracks compared to VRF did not increase with age in endodontically treated teeth.

In previous studies, it was reported that crack occurs more in mesial-distal direction (Udoye *et al.*, 2009), while VRF occurs in buccal-lingual(Moule *et al.*, 1999; Holcomb *et al.*). However, there was no prevalence in direction of fracture between cracked tooth and VRF in this study (table 1). Cracked tooth and VRF happen in bucco-lingual, mesio-distal or both directions in similar

manner. It was similar result with previous our study (Seo *et al.*, 2012).

It can be thought that the simple craze line or other symptomless fracture had lower portion in AAE category, because they will not be found unless patients visit with complaints. Still, for the pain causing fractured tooth, cracked tooth and VRF are the most frequent. Therefore, it is critical to understand various factors related to cracked tooth and VRF for correct diagnosis, appropriate treatment, and prevention. Early detection is most important in the prognosis of cracked tooth to prevent the propagation of the crack. If VRF is diagnosed, root resection or tooth extraction has to be considered. The limitation of this study was small numbers of VRF in 26 teeth. Further studies with larger number of sample from different ethnic group will be necessary.

## **V. Conclusion**

In this study, cracked tooth and VRF occurred in similar manner for sex and location of tooth, and showed differences in terms of restoration type/size and previous root canal treatment. Cracked tooth is prevalent in amalgam, gold, class I, II cavity restored teeth or naturally intact teeth. VRF was easily likely to occur with previous root canal treatment and crown restored tooth. This type of information is what can give guide to the dentist when diagnosing crack teeth, and further, can give guideline to make a treatment plan to prevent crack teeth.

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## 국문초록

### 임상적으로 가장 흔한 두가지 수직치아파절의

### 요인분석: 균열치아 vs. 수직치근파절

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이 찬 주

#### 목적

이 연구는 치아파절증 임상에서 가장 흔하게 나타나는 치관파절과 수직치근파절에 영향을 주는 요소들을 분석하는데 목적이 있다.

#### 연구자료 및 방법

총 172개의 치아 (146 크랙치아 와 26개의 수직치아파절) 이 본 연구에 이용 되었다. 분석 된 요소들은 나이, 성별, 치아번호, 치아 악궁, 충전 재료, 와동 크기, 와동 분류, 파절의 위치와 방향, 이전 근관치료의 유무 등이다. Categorical variable의 연관 요소들이 Fisher exact test를 통하여 비교 되었다. P 값이 0.05 다 큰 경우를 통계적으로 중요하다고 하였다.

## 결과

크랙치아와 수직치근파절은 성별, 나이, 치아번호에서 통계학적으로 유의한 차이를 보이지 않았다. 충전물이 없거나, 아말감, 금으로 충전된 치아에서 수직치근파절보다 크랙치아가 더 빈번하게 발견 되었다. 와동의 분류를 보면, 크랙치아가 class I 과 II 와동에서 더 높게 나타났었다. 또한, 교합면에 1/3 이상 크기의 와동에서도 크랙치아가 더 빈번하였다. 예전 근관치료경험이 없는 치아에서 가장 높은 크랙치아 비율이 나타났고 (92.8%) 수직치근파절은 근관치료경험이 있는 치아에서 더욱 빈번하게 나타났었다 (63.8%). 또한, 근관치료를 경험한 치아는 연령 증가에 따른 크랙발생율이 유의미하게 증가하

는 것을 보여주었다.

## 결론

크랙치아는 Class I,II의 금 수복복이 된 치아나, 전혀 수복되지 않는 자연치아에서 빈번히 발생하였다. 수직치근파절은 근관치료 및 금관관치료를 받은 치아에서 빈번 하였다. 이러한 두가지 다른 치아 파절의 요인을 이해하는 것은 더욱 정확한 진단과 치료계획을 세우는데 매우 중요하다.

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주요어 : 크랙치아, 수직치근파절, 다양한 요인, 충전 재료, 와동 분류, 근관치료

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