ORIGINAL ARTICLE

Efficacy of Contrast Medium-assisted Imaging in Diagnosing Cracked Tooth

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ABSTRACT

Introduction: This experimental study aimed to evaluate the efficacy of contrast medium-aided intraoral periapical radiographic imaging in the detection of cracked teeth and to determine optimal in-vitro compression force for crack detection. **Methods:** 27 extracted human lower premolar teeth were randomly divided into two groups: the control group, which was imaged using the conventional radiography and the experimental group which was imaged using a contrast medium (Iopamidol®). Both group were examined by transillumination to confirm the presence of a crack prior to imaging. A compression test using a Universal Testing Machine was used to induce the crack. Two dental clinicians blinded to the imaging technique evaluated the images and determined the presence or absence of cracks. **Results:** The force needed to produce a superficial crack ranges from 200N to 500N with a median compression force of 400N. The range of force to produce partial crack was 200N to 550N with the median force slightly higher than superficial crack which is 435N. The force to produce dentinal fracture ranges from 300N to 1100N with the highest median of 525N. The results showed that there were no visible cracks were detected in IOPA with/without contrast medium. **Conclusions:** The study did not find contrast-enhance IOPA to be effective in detecting cracks, but the study did establish the optimal median compression force values for inducing cracks which is between 400N to 525N. IOPA with contrast medium is not an effective diagnostic tool for cracked teeth compared to transillumination.
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Keywords: Cracked tooth, Transillumination, Radiograph,Contrast medium

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INTRODUCTION

Cracked or incomplete fractured teeth constitute a significant contributory factor to tooth loss in developing nations, along with dental caries and periodontal diseases (1). These teeth are alternatively referred to as cuspal fracture odontalgia, fissured fracture, incomplete tooth fracture, fissural fracture, crack lines, and greenstick fractures. The term "Cracked Tooth Syndrome" characterizes an unfinished or partial dentin fracture, occasionally extending into the pulp of a vital posterior tooth (2). Within the taxonomy of longitudinal tooth fractures, a cracked tooth is categorized alongside phenomena such as craze lines, fractured cusps, split teeth, and vertical root fractures.

Craze lines, for instance, manifest as visible lines on the enamel, typically present without symptoms, and do not obstruct the passage of light during transillumination. Teeth featuring fractured cusps exhibit a crown-to-dentin extension of the fracture terminating in the cervical region. Such teeth typically manifest mild pain upon biting and cast shadows when illuminated via transillumination. In contrast, a split tooth represents the ultimate outcome of cracked teeth. It is characterized by a mesiodistal line through marginal ridges extending from the crown to a subgingival location, leading to the separation of buccal and lingual cusps when probed by an explorer. Consequently, these teeth exhibit deep probing depths along both marginal ridges. Furthermore, a vertical root fracture originates in the root area and extends coronally. Teeth displaying vertical root fractures often have a history of extensive restoration and root canal treatment. Symptoms are typically mild and inconspicuous until the emergence of periapical pathologies (3).

The formation of cracks in teeth can be attributed to a multitude of factors, including inherent predisposing characteristics, parafunctional habits, and iatrogenic influences. Natural predisposing features, such as the steep inclination of cusps and fossa in upper premolar teeth, have been identified as contributing to crack formation (4). Additionally, parafunctional behaviors like bruxism and clenching, which subject patients to unconscious and prolonged occlusal trauma, can also increase the risk of crack development (5). Iatrogenic causes, involving the use of rotary instruments and cavity preparation during dental procedures, have been recognized as potential sources of tooth cracks (5). Furthermore, studies have emphasized masticatory actions as a predominant cause of vertical tooth fractures, particularly in patients who consume brittle and hard foods, such as ice and hard candy (6). Clinically, patients with cracked teeth often present with hypertrophied masticatory muscles and evidence of occlusal wear resulting from excessive occlusal forces (7). The orientation of the crack may manifest in a mesiodistal direction, affecting one or both marginal ridges, as well as in a buccolingual orientation (8).

The susceptibility to tooth cracks is not uniform across different tooth types. Mandibular molars are found to exhibit a higher propensity for developing cracks, followed by maxillary molars and mandibular premolars (1). Notably, lower second and first molars are the most vulnerable to crack formation, with upper premolars also showing an increased susceptibility (6,7). The likelihood of a tooth being affected by cracks is often associated with the presence of extensive restorations (6,7). Moreover, the duration of exposure to risk factors and patient habits can significantly impact the likelihood of crack formation, with posterior teeth being particularly susceptible due to their proximity to the mandibular fulcrum, which subjects them to greater occlusal forces (7, 9).

Timely identification of dental cracks holds paramount importance for the overall prognosis of the affected tooth. Early diagnosis is instrumental in preventing the progression of cracks into more severe conditions, including full-fledged fractures, pulpal inflammation, pulpal necrosis, periodontal diseases, and the most dire consequence, tooth loss. Delayed detection of dental cracks can lead to heightened problems, prolonged discomfort, and increased pain over time. The specific symptoms of a crack are contingent upon the pulpal and periapical conditions of the tooth (10). These symptoms can range from relatively mild, such as reversible pulpitis, which may be managed through a simple restoration, to more severe forms, such as irreversible pulpitis or pulp necrosis.

Cracks in teeth can serve as potential pathways for virulent microorganisms to infiltrate the pulpal tissue, thereby triggering pulp inflammation and subsequent necrosis. In cases where the crack causes reversible pulpitis, approximately 80% of cases can be conservatively managed without necessitating root canal treatment. The prognosis, however, is contingent on whether the crack extends onto the pulpal floor, with consideration given to extraction or replacement if the situation warrants it. It's imperative to underscore that the management and treatment plan should not be solely reliant on the presence of a crack but should take into account pulpal and periapical diagnoses (3).

Various methods are available for detecting dental cracks, encompassing visual examination, Fibre-optic transillumination (FOTI), cone beam computed tomography (CBCT), swept-source optical coherence tomography, infrared thermography (VibroIR), dental radiography, microscopic evaluation, and quantitated light-induced fluorescence technology. The visual examination represents a commonly employed initial method for identifying apparent cracks, facilitated by direct visualization aided by dental mirrors and adequate lighting. FOTI, involving the projection of a light beam onto tooth structures to reveal cracks, is often considered an ideal or gold standard for crack detection (11). It operates on the principle of physics that light penetrates a substance until it encounters a void, at which point it reflects, creating discernible shadows on the tooth bisected by the crack. However, this method may occasionally face challenges in distinguishing cracks from enamel craze lines and in detecting cracks situated subgingivally or in interproximal regions (12).

Although cracked teeth are prevalent, their detection can be challenging, especially when the cracks are too minute to be discerned through visual examination or radiographic imaging. Conventional radiography, due to its limited sensitivity, proves ineffective in identifying early-stage cracks. Typically, radiographic imaging can only detect larger or more advanced cracks with resolutions exceeding 100 μm (13), limiting its utility to cases of substantial cracks or fractures. Staining the tooth's surface with dyes or contrast media serves to enhance the visibility of cracks and improve their detection. These substances infiltrate the cracks, rendering them more conspicuous on radiographs.

Existing research has revealed the limited efficacy of visual examination, transillumination, and conventional radiography in detecting early or deep-seated cracks. Therefore, the present study aims to establish an optimal in-vitro compression force for crack detection and assess the effectiveness of contrast media in intraoral periapical radiographs (IOPA) for detecting cracks within teeth.

MATERIALS AND METHODS

Ethical Approval

The study received ethical approval from the Committee for Ethics in Research, Faculty of Dentistry, Universiti Teknologi MARA, Malaysia.

Sample Selection and Preparation

A total of 27 extracted mandibular premolar teeth were selected for this investigation. Teeth presenting with dental caries, dental fluorosis, intrinsic discolouration, severe attrition, obvious defects, restored surfaces, or having undergone endodontic treatment were excluded from the study. The selected teeth were preserved in a solution of thymol crystals diluted with distilled water, then sterilized in a steam autoclave for 30 minutes at 121°C and 151 psi in saline solution to ensure their sterility. Extrinsic stains, plaque, and calculus were meticulously removed using a hand scaler. To prevent dehydration, the teeth were immersed in a normal saline solution at room temperature throughout the study. Each sample was visually inspected using a stereomicroscope at magnifications of 0.67x, 2.5x, and 4.5x and transilluminated before undergoing further procedures (Figure 1). Teeth showing visible dentin cracks were excluded from the study. All samples were systematically labelled, and the roots were coated with an adhesive synthetic rubber compound to simulate the periodontal ligament. Subsequently, the samples were mounted vertically in self-cure acrylic resin, positioned 2 mm below the cementoenamel junction.

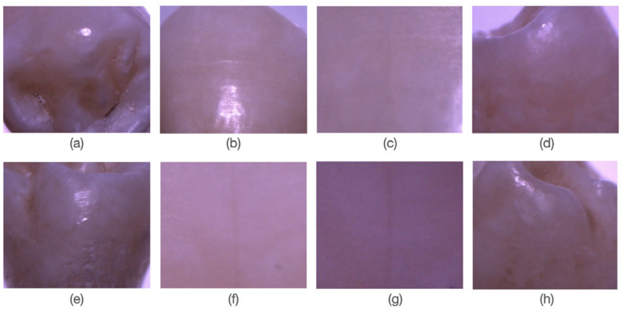

Figure 1: Images under stereomicroscope of a sample with different surfaces and magnifications prior to crack induction. (a) occlusal view with 0.67 magnification, (b) buccal view with 0.67x magnification, (c) buccal view with 2.5x magnification, (d) mesial view with 0.67x magnification, (e) lingual view with 0.67x magnification, (f) mesial view with 2.5x magnification, (g)mesial view with 4.15x magnification, (h) distal view with 0.67x magnification.

Induction of Artificial Cracks

Artificial cracks were induced using a Universal Testing Machine. The samples were centrally positioned on the loading platform and compressed at a rate of 2 mm/min until the tooth exhibited a crack. The computer automatically recorded the maximum loading force at the point of crack initiation for each sample.

Detection of Artificial Cracks using Transillumination, IOPA with/without Contrast Medium (Iopamidol®)

The artificially induced cracks in the teeth were assessed using three distinct methods: transillumination, intra-oral periapical (IOPA) radiography with or without a contrast medium. Transillumination was performed using a specialized pen (MicroLux) under 2.5x magnification with the aid of a surgical microscope, and images were captured for documentation purposes (Figure 2). For IOPA, a paralleling technique was employed (Figure 3), utilizing an X-ray exposure setup of 250 kVp, 8 mA, a cylindrical locator with a 40-cm focal length, and an exposure time of 0.125 seconds. The ALARA (as low as reasonably achievable) principle was strictly adhered to to determine the shortest exposure time to yield an optimal radiographic image with satisfactory brightness and contrast.

A contrast medium, Iopamidol®, was employed for certain IOPA radiographs to enhance the visualization of the region of interest. This iodinated, water-soluble,

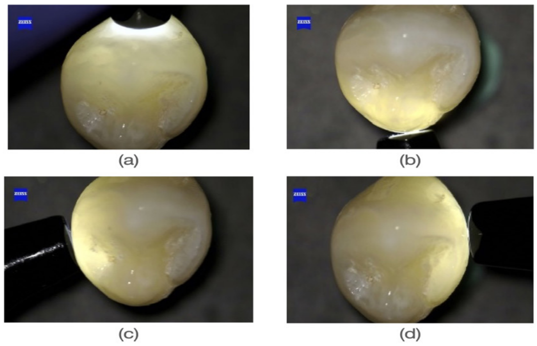

Figure 2: Images of cracks detection using transillumination under 2.5x magnification (a) buccal view, (b) lingual view, (c) distal view, and (d) mesial view.

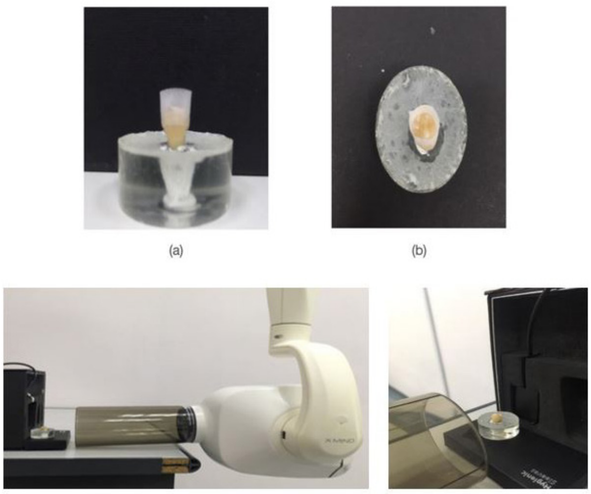

Figure 3: Contrast medium (Iopamidol®) was left for 5 minutes on the occlusal surface of the tooth before IOPA was taken. Paralleling technique for imaging the sample was used in this study.

non-ionic contrast agent was applied to the tooth's surface before radiographic imaging. To achieve this, the coronal portion of the samples was isolated using tape, and the contrast medium was allowed to absorb on the occlusal surface for a period of 5 minutes (Figure 3). Subsequently, IOPA radiographs were taken after the residual contrast medium had been removed. Both sets of radiographic images, with and without contrast medium, were thoroughly examined to identify any observable changes (Figure 4 & 5). Two calibrated dental clinicians blinded to the imaging technique evaluated the images and determined the presence or absence of cracks.

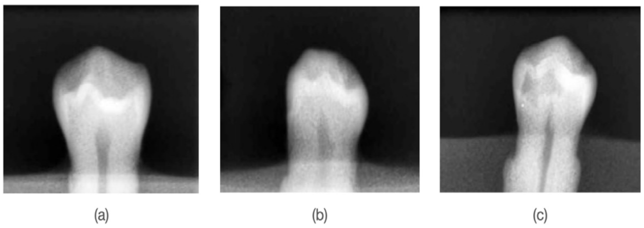

Figure 4: IOPA images without contrast medium for samples with (a) superficial crack, (b) partial crack, (c) fractured lingual cusp. No crack lines can be seen from these images.

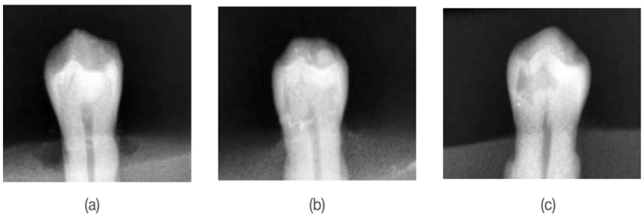

Figure 5: IOPA images after contrast medium was applied on the occlusal surface of samples with (a) superficial crack, (b) partial crack, (c) fractured lingual cusp. No crack lines can be seen from these images.

Statistical Analysis

In the statistical analysis of this study, IBM SPSS Statistics 23 software was employed to assess the forces required to induce distinct types of dental cracks, namely superficial, partial, or dentinal fractures. The categorization of these samples was based on the classification of tooth cracks established by the American Association of Endodontics (AAE) (3).

The classification system utilized was as follows:

Score 0: Indicated the absence of any observable crack.
Score 1: Characterized by the presence of craze lines or superficial cracks limited to the enamel, which did not obstruct the passage of light during transillumination.
Score 2: Defined as cracks involving dentin, which could propagate mesiodistally or buccolingually, accompanied by the presence of shadows observable during transillumination. Notably, the Score 2 cracks observed in this study were confined to incomplete dentinal cracks visible on only one surface.
Score 3: Designated fractures affecting the cusps of the tooth, discernible as shadows under transillumination.

To ascertain the distribution of each type of crack generated in the study, descriptive statistical analysis was performed. This method allowed for a comprehensive evaluation of the percentages associated with each distinct category of tooth crack, thereby facilitating a detailed assessment of the outcomes.

RESULTS

In the course of this investigation, a total of 27 teeth afflicted by cracks of varying degrees were subjected to analysis. The evaluation involved the determination of the forces necessary for the initiation of distinct types of cracks. For the induction of superficial cracks, the required force ranged from 200N to 500N, with a median force of 400N, as summarized in Table I. Likewise, the force range for the inception of partial cracks spanned from 200N to 550N, with a slightly elevated median force of 435N compared to superficial cracks. Conversely, the force threshold for the development of dentinal fractures encompassed a broader spectrum, extending from 300N to 1100N, with the highest median force recorded at 525N.

Table I: Median maximum loading force for partial, superficial crack and dentinal fracture

Median loading force (N)				
		Maximum loading force for partial crack	Maximum loading force for superficial crack	Maximum loading force for dentinal fracture
N	Valid	6	11	10
	Missing	21	16	17
Median (N)		435.0	400.0	525.0

The examination revealed that superficial cracks primarily affecting the enamel (Score 1) were discernible in 40.7% of the investigated samples. A smaller subset, approximately 22.2% of the samples, exhibited partial cracks that involved the dentin (Score 2), while the remaining 37% of the samples exhibited substantial fractures that penetrated the dentin (Score 3). To categorize these findings, the AAE classification of cracks was employed, and the identification of cracks was corroborated through transillumination. The distribution of different types of cracks observed under transillumination is depicted in Table II. It is noteworthy that the application of intraoral periapical radiography (IOPA) failed to detect any of the observed cracks, both with and without the use of a contrast medium, as detailed in Table II. Consequently, all samples exhibited no visible cracks under IOPA, whether a contrast medium was employed or not. The results obtained from repetitive IOPA with a contrast medium closely paralleled those obtained from IOPA without a contrast medium, as recorded in Table II.

Table II: Percentage of different types of cracks that can be by transillumination and in radiograph with a contrast medium

		Transillumination			
		Frequency	Percent (%)	Valid precent (%)	Cumulative percent (%)
Valid	Superficial				
	Partial				
	Farcture				
	Total				
		Radiograph with contrast medium			
		Frequency	Percent (%)	Valid precent (%)	Cumulative percent (%)
Valid	Visible crack line with contrast	0	0	0	0

DISCUSSION

The findings of this study indicate that there is no specific median force capable of causing complete dentinal cracks. Instead, the induced cracks primarily exhibited partial penetration into the dentin or progressed to manifest as dentinal fractures. This observation could be attributed to the influence of tooth cusps inclination (13). Interestingly, the attempt to induce cracks using force levels in the range of 50N-60N, as determined by a previous study, yielded no cracks in the current investigation. This discrepancy may be attributed to the utilization of different types of teeth, specifically maxillary incisors (14). It is worth noting that masticatory forces vary across different tooth types, with anterior teeth requiring less force compared to posterior teeth. Premolars, in particular, experience higher masticatory forces due to their role in tearing and grinding food. Furthermore, the study found that teeth with steeper inclinations are more prone to cracking and fracturing.

Moreover, the results also shed light on the limitations of radiographs in crack detection. The cracks induced in this study were predominantly confined to the enamel and had not completely extended into the dentin. As mentioned by Mathew S et al., these cracks typically propagate in a mesiodistal direction parallel to the plane of the radiographic film (5). To visualize cracks effectively in radiographs, they should ideally be oriented in a buccolingual direction perpendicular to the film. However, the study's radiographic image resolution was restricted to 100 μm (12), making the detection of cracks smaller than 100 μm challenging using this method.

Contrast medium-enhanced radiographs also failed to reveal detectable cracks in this study, potentially due to several factors. Firstly, the orientation of the cracks, primarily in the mesiodistal direction, could hinder the diffusion of the contrast medium, especially when the crack is incomplete or the space within the crack is insufficient (15). Moreover, even if the contrast medium were to infiltrate the crack, the resulting radiopaque line in the radiographic image might overlap with the radiopacity of the enamel. The effectiveness of the contrast medium-enhanced radiography is influenced by various factors such as the type of contrast medium used, the concentration of the contrast medium, the duration of the exposure to the contrast medium (16).

In contrast, clinical detection of cracks using transillumination proved useful for locating cracks, but it did not provide adequate information about the depth of the crack. A surgical operating microscope was found to be a valuable adjunct to transillumination, enhancing the operator's ability to visualize the crack more effectively. Consequently, the use of intraoral periapical (IOPA) radiographs with a contrast medium did not yield positive findings for all three types of tooth cracks under investigation. The use of higher resolution imaging technique like cone-beam computed tomography (CBCT) with contrast medium sodium iodide and dimethyl sulfoxide has been shown to be effective in crack detection compared to micro computed tomography (17), however patient has to be subjected to a higher exposure of radiation compared to intra-oral periapical radiograph technique.

This indicates that contrast medium-enhanced radiography, while a potentially useful diagnostic tool for tooth cracks, may not be effective in all cases and should be used in conjunction with other diagnostic methods. Dentists should also keep in mind the limitations of contrast medium-enhanced radiography when interpreting radiographic images for tooth cracks. Additionally, future research is needed to improve the effectiveness of contrast medium-enhanced radiography in detecting tooth cracks, possibly through the development of contrast media that can more effectively diffuse into incomplete cracks or through the use of higher resolution imaging techniques.

Despite these challenges, this study successfully established the optimal median compression force, which could serve as a valuable reference for future in-vitro studies aimed at inducing cracks. This optimal median compression force can be used as a reference value for future studies aimed at inducing cracks in vitro. It can also serve as a starting point for the development of force threshold values for potential crack induction studies in the future. This information is essential for researchers to accurately mimic clinical conditions in their in-vitro studies, leading to more robust and reliable data. In conclusion, the establishment of the optimal median compression force for inducing tooth cracks in vitro is a valuable contribution to the field of dental research. This finding will facilitate the development of force threshold values for future studies aimed at inducing cracks and ultimately lead to better detection and treatment of tooth cracks.

CONCLUSION

In conclusion, the findings of this study highlight the complexity of tooth crack detection and highlight the limitations of currently available diagnostic tools. Dentists should be aware of the potential for tooth cracks and should use a comprehensive approach, incorporating multiple diagnostic methods, to ensure early and accurate detection. Further research is needed to investigate the development of more sensitive diagnostic tools and to explore the effects of various factors on tooth crack formation, such as tooth inclination, dental restoration materials, and occlusal forces.

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The authors deny any conflicts of interest related to this study.

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