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REVIEW ARTICLE

Guidelines to enhance the interpretation of two-dimensional periapical radiographic images in endodontics

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ABSTRACT

Radiology is an indispensable tool in the clinical practice of endodontics because most structures that harbor diseases are invisible to the naked eye. As a result, the use of periapical radiographs before, during, and after root canal treatment is essential in order that anatomical details, canal length, obturation quality, and tooth and bone pathology can be identified and monitored. The purpose of this article is to discuss the guidelines that should be followed to enhance the interpretation of periapical radiographic images in endodontics and to facilitate the identification of root and root morphology, relationship of the teeth to the surrounding anatomical structures and pathological changes in the radicular and peri-radicular areas.

Key words
Endodontics, guidelines, interpretation, periapical radiography, root canal

INTRODUCTION

Success of root canal treatment depends on a number of factors including adequate knowledge of the root and root canal morphology, proper diagnosis of the pulp and periapical condition, and thorough preparation and obturation of the complex root canal space.[1,2] The use of periapical radiographs before, during, and after treatment is essential in order that anatomical details, canal length, obturation quality, and tooth and bone pathology can be identified and monitored.[1]

The complex anatomy of the teeth, their surrounding structures as well as various pathological patterns may render diagnostic procedures and treatment monitoring difficult.[3] Therefore, clinicians must be trained to identify normal anatomical landmarks and variations due to pathology.[1] The purpose of this article is to discuss the guidelines that should be followed to enhance the interpretation of periapical radiographic images in endodontics [Diagram 1].

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GUIDELINES TO ENHANCE THE INTERPRETATION OF TWO-DIMENSIONAL PERIAPICAL RADIOGRAPHIC IMAGES

Knowledge

Knowledge – root and root canal morphology

In the past decade, numerous reports on the identification of external and internal anatomical radicular variations have been published.[4] Investigations always refer to "complexity" and "variability" to describe the morphology of human dentition.[5,6] However, the situation is different when such subject comes into clinical practice, and the increased prevalence of missed canals continues to be the main cause of root canal treatment failures.[2,7,8]

An important "psychological tip" for clinicians is to ignore the absolute confidence of the pre-estimated number of roots and root canals. Knowledge of normal and unusual anatomy, precise prediction, and clinical thoroughness are essential requirements for a successful endodontic practice.[9,10]

Current literature shows a paradigm shift in the root and root canal morphology of human dentition.[4] In addition to normal anatomical variations, dental practitioners should be aware of the occurrence of three-rooted mandibular molars (which is currently becoming a common normal morphologic variant in Asian traits), middle mesial canals in mandibular molars, three-rooted/-canalled maxillary premolars, double-rooted/-canalled anteriors

and mandibular premolars, and four-rooted maxillary molars.[2,4,6,9,11-15]

Knowledge – surrounding vital structures

In addition to root and root canal morphology, clinicians should be aware of the relationship of the teeth to the surrounding anatomical structures. The major anatomic considerations of importance to endodontics involve (a) the incisive foramen, (b) the mental foramen and its neurovascular bundle, (c) the maxillary sinus, and (d) the mandibular canal and its neurovascular bundle. The clinician must exercise good judgment to avoid potential injury of these anatomic structures during orthograde and retrograde endodontic procedures.

The incisive foramen, located in the midline just palatal to the central incisors and directly beneath the incisive papilla, is one of the most commonly misinterpreted anatomic structures for periapical lesions related to maxillary central incisors.[16]

The mental foramen is visible on 75% of the horizontal periapical radiographs.[17] The position of the mental foramen is usually mesial and below the radiographic apex, or in line with the longitudinal axis, of the second mandibular premolar.[17,18] This radiographic appearance may result in a misdiagnosis of a radiolucent lesion in the apical area of mandibular premolar teeth.[19]

The close relationship between the roots of maxillary molars/premolars and the floor of the maxillary sinus is common. Accurate perception and consideration of this close relationship would prevent the occurrence of some serious complications such as sinus inflammation or perforation due to over-instrumentation or extrusion of endodontic materials such as irrigants, intra-canal medicaments, or root canal filling materials.[12,20,21]

Similar to maxillary molars, the anatomical relationship of mandibular molars to vital structures is of prime importance. When the root apices of mandibular molars show close proximity to the mandibular canal, meticulous attention should be given to avoid over-instrumentation and extrusion of irrigants, medicaments and root canal sealers to prevent local injury to the nerve, which may require complicated surgical intervention to prevent permanent nerve damage.[12]

Although the alveolar bone that surrounds the roots of mandibular second and third molars is often free of confounding anatomical structures which often leads to an unquestionable diagnosis of periapical changes, the variations in trabecular pattern in this area is a frequent source of misdiagnosis of apical lesions that do not actually exist.[22]

Knowledge – pathological changes in the radicular and peri-radicular areas

Clinicians should also be aware of (i) pathological changes in the pulp, including abnormal pulp calcification due to caries or trauma and internal root resorption, (ii) pathological changes in the root, including root fractures, external root resorption and palato-gingival grooves, and (iii) pathological changes that could occur in the periapical area including

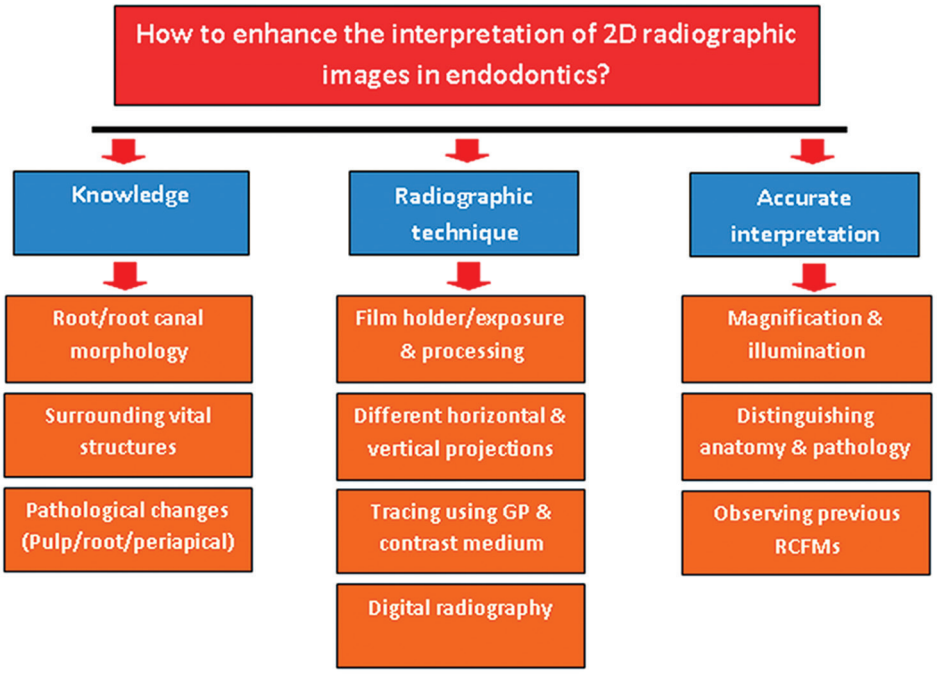

Diagram 1: Factors affecting the interpretation of two-dimensional periapical radiographic images in endodontics

apical periodontitis, condensing apical osteitis, and lesions of nonendodontic origin.

Apical periodontitis lesions generally have an etiology that is associated with necrosis and infection of the root canal system.[23] Apical periodontitis lesions are usually identified radiographically as a widening of the periodontal ligament space (early response) or a droplet-shaped radiolucency located around the apex of the affected tooth (chronic response). Notably, widening of the periodontal ligament space is also a common consequence of increased mobility, marginal periodontal inflammation, traumatic occlusion, or orthodontic treatment.[22]

Previous reports have described the occurrence of nonendodontic lesions mimicking apical periodontitis and their misdiagnosis.[23-25] Lesions of neoplastic sources (such as ameloblastoma, ossifying fibroma and keratocystic odontogenic tumor [Figure 1]), cystic/cystic-like lesions of nonendodontic origin (such as lateral periodontal cyst and traumatic bone cyst), and central giant cell lesions might radiographically mimic lesions of endodontic origin.[22-24] Rigorous clinical and radiographic exams are essential to reach the correct diagnosis. The presence of teeth with a vital pulp excludes the possibility of chronic apical periodontitis.[24] However, teeth associated with periapical nonendodontic lesions could also present with pulp necrosis or have been endodontically treated, which can lead to misdiagnosis and an ineffective treatment protocol.[24,26] Thus, periapical lesions that do not heal after adequate root canal treatment or have an unusual radiographic image should be submitted to biopsy or complete excision.[24,26] Furthermore, all periapical tissue excised after any surgical procedure should be subjected to histopathologic analysis.[24,26,27]

Optimization of the radiographic technique

In all endodontic cases, "a well-exposed and well-processed" intraoral periapical radiograph of the root and periapical region is mandatory.[2,28] Artifacts and image distortion caused by improper horizontal/vertical angulation, movement of the patient, incorrect film placement, and inappropriate processing procedure should be avoided. Notably, a poor quality radiograph not only fails to yield diagnostic information, but also, and more seriously, causes unnecessary radiation of the patient.[28] The use of "film holders" has two distinct advantages. First: A true image of the tooth, its length and anatomical features is obtained. Second: Subsequent films taken with the same holder can be more accurately compared during assessment of the degree of healing of a peri-radicular lesion.[28]

If a sinus tract is present, then a 30–40 sized gutta-percha point should be inserted and threaded, by rolling it gently between the fingers, as far along the sinus tract as possible. If a radiograph is taken with the gutta-percha point in place, then an area of bone loss showing the cause of the problem can be detected [Figure 2].[28]

Preoperative radiographs with more than one horizontal projection can provide some clues to the bucco-lingual dimensions of the tooth and its surrounding structures. Such views are of prime importance in the following clinical situations:

- The incisive and mental foramina that may overlap over central incisors and mandibular premolars, respectively, and may mimic a periapical lesion, can be distinguished [Figure 3a and b]
- The presence of accessory roots and root canals can be identified [Figure 4]
- Although differentiation between internal and external root resorption is possible in periapical radiographs (the outline of the root canal is usually distorted in internal root resorption, however in external root resorption, the root canal outline appears normal and can usually be observed "running through" the radiolucent defect [Figure 3c and d]), in some occasions, changing the horizontal angulation is useful to differentiate between both types of resorption in which internal root resorption appears close to the canal whatever the angulation of the X-ray.[29] In addition, distinguishing if the external root defect is buccal or lingual/palatal is possible using the buccal objective role[29]
- Conventional radiographic interpretation of maxillary molars may have many challenges because of possible superimposition of other anatomical structures, such as the zygomatic arch and the floor of the maxillary sinus.[2] Preoperative radiographs with more than one horizontal projection aid in the accurate detection of the periodontal ligament outlines, thus facilitating the interpretation of the external root anatomy.[2]

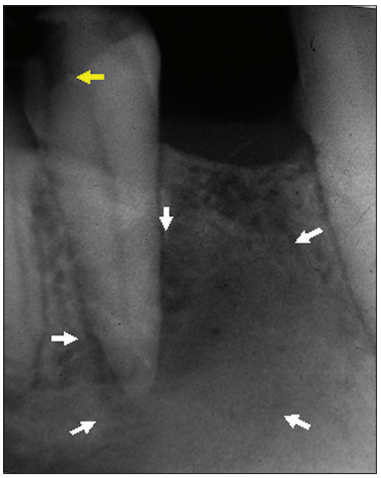

Figure 1: A periapical radiographic image showing large periapical radiolucency related to the root of a carious mandibular second premolar. The tooth was root canal treated, and the lesion was surgically excised. Histopathological examination revealed that the lesion was "keratocystic odontogenic tumor"

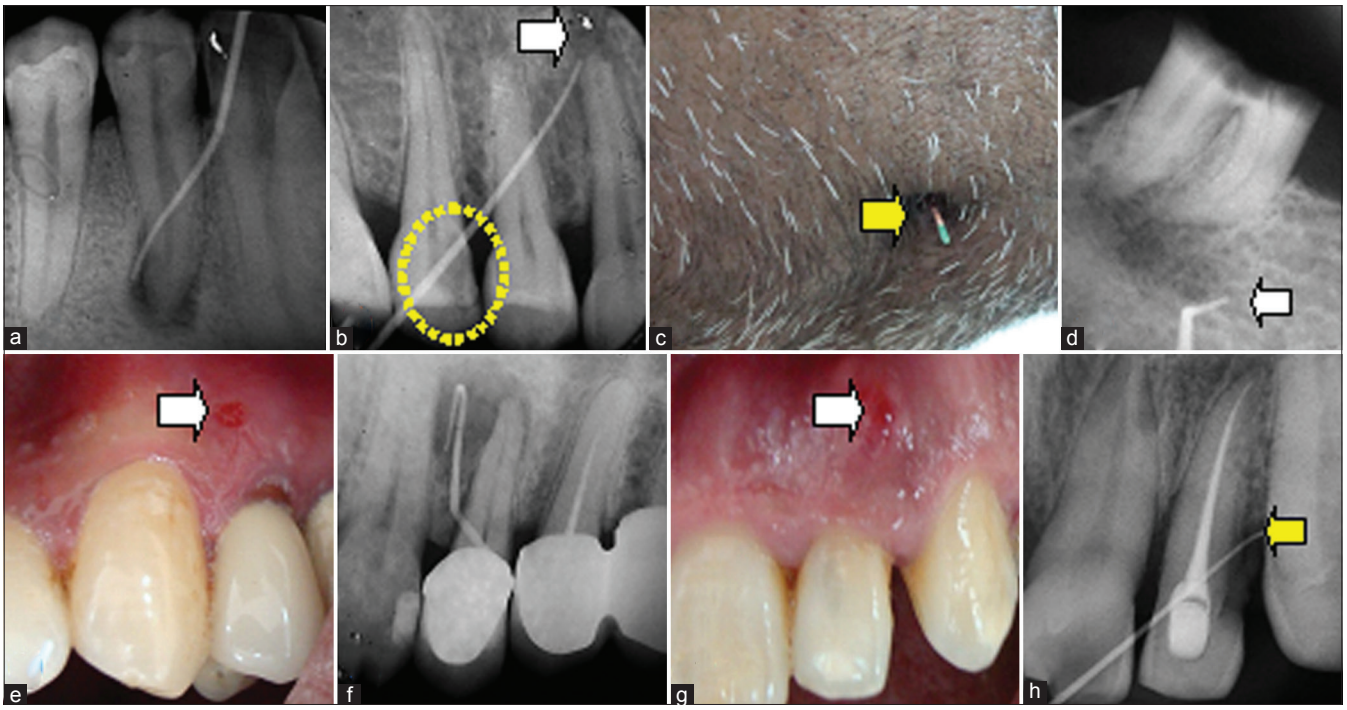

Figure 2: The importance of tracing sinus/fistula using gutta-percha points. (a) Periapical radiolucency related to a sound mandibular second premolar. (b) A sinus tract that was suspected to be related to a badly decayed maxillary second premolar. In fact, it was related to a sound maxillary canine (white arrow). (c and d) Tracing of an extraoral sinus that is related to a mandibular molar. (e and f) Tracing of a sinus related to a crowned maxillary first premolar. (g and h) Tracing of a fistula related to the root of a maxillary lateral incisor having a palato-gingival groove (yellow arrow)

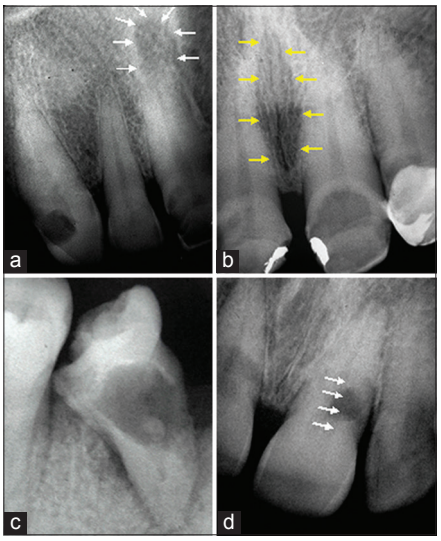

Figure 3: (a) Periapical radiograph showing periapical radiolucency related to a maxillary central incisor (white arrows). (b) Changing the horizontal angulation reveals an overlap of the incisive foramen over the root of the incisor (yellow arrows). (c) Internal root resorption causing disruption of the outline of the root canal. (d) The normal outline of the root canal can be identified (white arrows), if the root resorption is external

The darkening appearance in the roots of mandibular molars (increased radiolucency due to impingement of the mandibular canal on molar roots) is one landmark of a close relationship of the roots to the mandibular canal.[12] Apart from this landmark, changing the axial angulation would help in determining the bucco-lingual relationship of the mandibular canal to the roots. If the straight on and over axial views did not result in any change in the radiographic appearance of the overlapped canal on the roots, then a close relationship should be suspected.[12]

The application of contrast medium (such as Hypaque and Iohexol) inside the root canals has been reported to enhance the radiographic interpretation of the root canal morphology.[30] In addition, it has been found beneficial for investigating the penetration of root canal irrigation solutions *in vivo*.[31] Some years ago, an irrigation solution called "Ruddle solution" was formulated.[32] The Ruddle solution is a combination of 5% NaOCl, 17% EDTA and Hypaque (a water soluble, radiopaque, contrast solution). The progressive solvent action of NaOCl is supposed to clear out the contents of the root canal system thus enabling the iodine portion of the composition to flow into the vacated space. The aim of this radiopaque solution is to visualize root canal system anatomy, distinguish between internal and external resorption defects, assist in the diagnosis of fractures, identify the size and position of perforations, visualize blocked and ledged canals, and monitor the shape and remaining wall thickness during canal preparation.[32] Future studies are warranted to validate the efficiency of this irrigation solution in experimental and clinical settings, and to examine potential interactions between irrigants in this combination, and with other irrigation solutions used in endodontics.[33]

The application of digital periapical radiography in endodontics is advantageous because it provides real-time image display, reduced radiation exposure and ease of archiving.[34] However, the use of some relatively thick sensors would increase the probability of gag reflex, especially at the third molars.[12]

Guidelines for accurate interpretation

Magnification and illumination are essential diagnostic tools in endodontic practice. Therefore, using a magnifying device or loupes during interpretation of radiographs is recommended because some invisible details may become evident once magnified (this property is a common option in digital radiography software). Using an even light source and blocking out peripheral light are also advantageous.[2]

The external and internal morphological features of teeth scheduled for endodontic treatment should be identified accurately. Two periodontal ligament spaces on one side of a root or crossing of the periodontal ligament space over the root usually indicate the existence of an accessory root. The appearance of a "break point" or abrupt diminishing in the root canal indicates the presence of a root canal bifurcation [Figure 4a-c] (sometimes the main canal divides into more than 2 root canals[10]). Some of the other landmarks could be the eccentric location of an endodontic file on a radiograph during working length determination.[10] Root dilacerations can be detected easily.

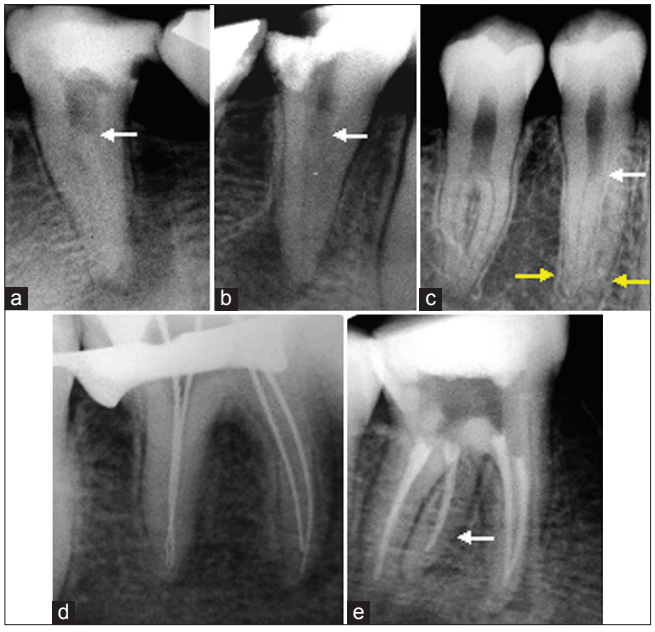

Figure 4: (a and b) "A break point" (white arrow) in the outline of the root canal is a landmark for the presence of multiple canals. This can be observed bilaterally. (c) Double-rooted mandibular premolars can be easily identified if the roots are located mesio-distally (second premolar - left). The presence of a break point (white arrow) together with tracing the periodontal ligament spaces (yellow arrows) could aid in the detection of accessory roots in other directions (first premolar - right). (d and e) Changing the horizontal angulation can also separate the overlap of disto-lingual roots (white arrow) on the disto-buccal roots

Apical periodontitis is an inflammation of the periodontium at the portals of entry of the root canal system.[35] Typically, the lesion is located at the root apex. Radiographically, the lesion appears as a droplet-shaped radiolucency at the apex. Deviation of the lesion from the long axis of the tooth is an indication that the portal of exist of the root opens laterally [Figure 5]. Notably, lesions may develop at lateral and furcal locations because pulp-periodontal communications may exist at various levels along the root surface.[35,36]

Observing the outline of filling material inside the root canal system after obturation is of particular importance. Obturation material (root canal sealer and thermoplasticized gutta percha if applied) can propagate from the filled canal into the missed canal through inter-canal communications, if present, and appear in the postoperative radiograph as a radiopaque line that connects to an empty space.[10] Obturation material that is not centered within the root may also be a sign of a missed canal.[8] Tracing the outline of the obturation material in retreatment cases may indicate the presence of missed canals [Figure 6].

LIMITATIONS

Periapical radiographs have certain limitations including anatomical noise, two-dimensionality and geometric distortion.[37] Three-dimensional imaging, such as cone beam computed tomography (CBCT), was adapted

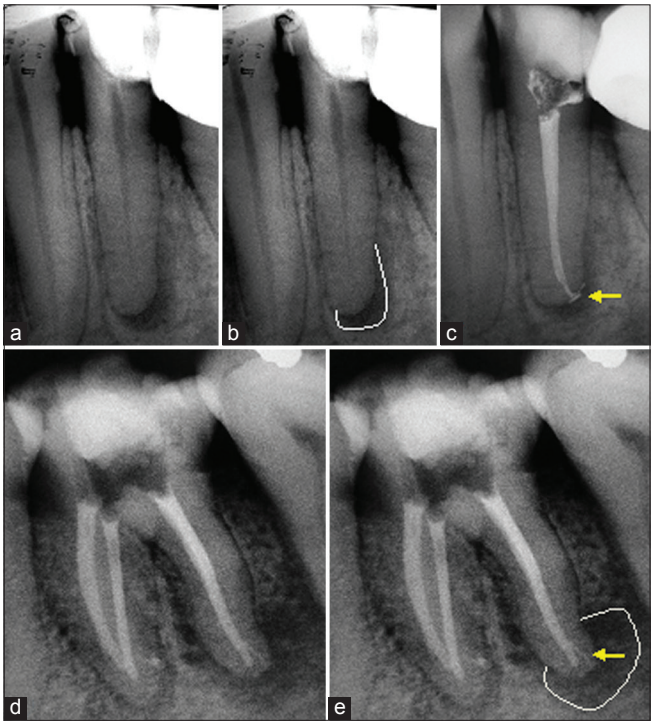

Figure 5: Eccentric location of the periapical radiolucency (deviation from the long axis of the root) is a landmark for either (a-c) a lateral opening of the main foramen (yellow arrow), or (d and e) the presence of lateral canals (yellow arrow)

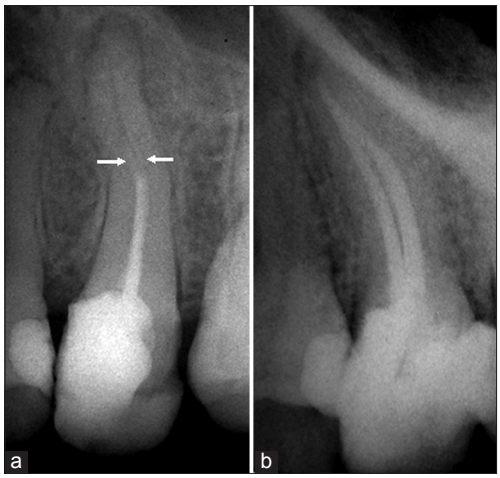

Figure 6: (a and b) Careful tracing of the old obturation material (white arrows) could aid in detecting a missing canal

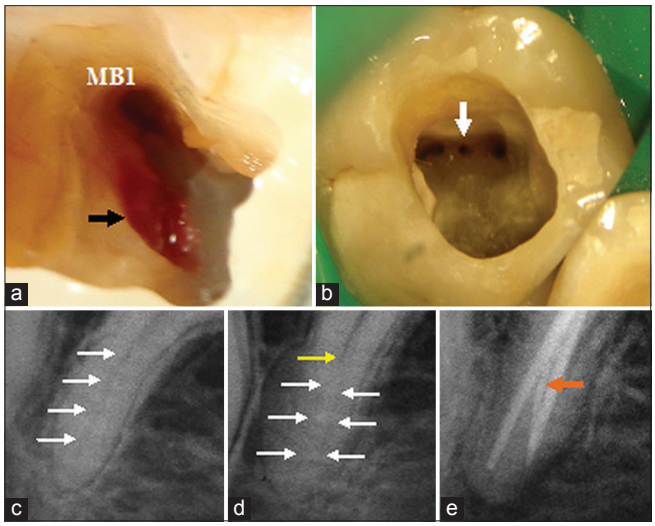

Figure 8: Clinical exploration is essential together with radiographic interpretation. (a) A bleeding point (black arrow) is an indication for the presence of MB2 in maxillary molars. (b) Middle mesial canals can be detected after careful exploration of the groove between MB and ML canals. (c) Periapical radiograph showing a single canal in the distal root of a mandibular molar. (d) A "break point" was evident after changing the horizontal angulation (yellow arrow), and two separate canals were detected. (e) During clinical exploration, a third middle distal canal (orange arrow) was identified

for dental applications to overcome the limitations of periapical radiographic images by eliminating the superimposition of anatomical structures, and improving the observation of bone structures and their relationship with adjacent anatomical structures.[37]

Cost, availability and radiation dose considerations are, however, the main challenges to the adoption of CBCT for extensive clinical applications.[38,39] In addition, CBCT may show some misleading findings.[40] Therefore, CBCT should not be used for routine examination, and it is only indicated when conventional radiographs provide limited information, and further details need to be identified.

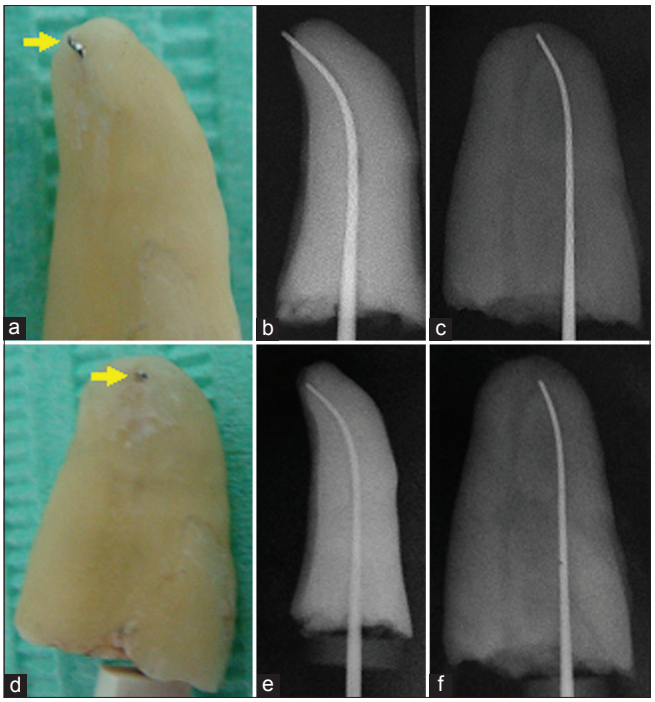

Figure 7: Radiographic interpretation should be augmented with clinical assessment during working length determination. (a-c) An SS hand file adjusted 1 mm beyond the apex (yellow arrow). The over-extension could be detected radiographically if located in a mesio-distal direction (b), but it will appear within the confines of the root if located in a bucco-lingual direction (c). (d-f) Placing the file flushing at the root apex (yellow arrow) could also be misinterpreted as a short working length (f). Therefore, the use of an electronic apex locator is essential

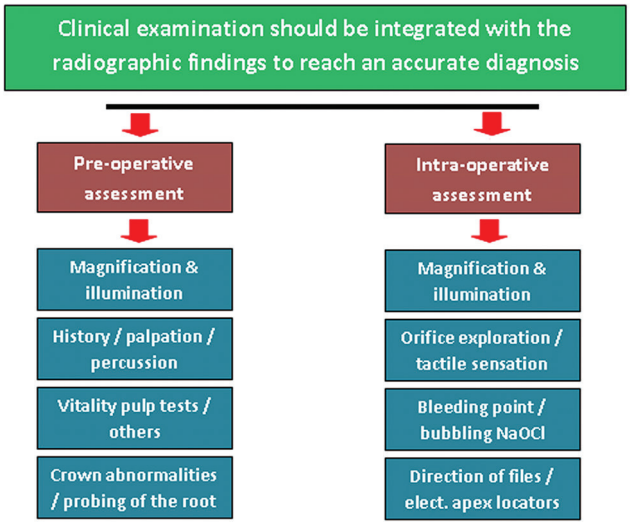

Diagram 2: Accurate diagnosis is a combination of appropriate interpretation of radiographic images and careful pre- and intra-operative assessment procedures

Notably, information obtained from radiographic images is valuable, but still incomplete, and should always be integrated with a careful clinical examination [Diagram 2], preferably under magnification [Figures 7 and 8].[8] Considering these aspects, reducing the amount of

diagnostic confusion and inappropriate treatment plan is possible.

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