RESEARCH

Pre-operative diagnostic radiograph interpretation by general dental practitioners for root canal treatment

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Objectives: The aim of this study was to evaluate which radicular radiographic features general dentists want to interpret, determine which of the radicular radiographic features general dentists interpret and which ones they miss in a diagnostic radiograph and correlate how accurately general dentists are able to interpret radiographic features.

Methods: 20 general dental practitioners were selected and given 2 sets of questionnaires. The first set asked them to fill out the findings they would elucidate in a diagnostic radiograph while the second set consisted of 30 randomly selected intraoral radiographs to interpret.

Results: In the first set of questionnaires, more than 50% of dentists said they would interpret periapical changes, calcification, root curvature and the number of root canals. Less than 50% said they would interpret canal morphology, open apex, resorption, fracture, number of roots and lamina dura. In the second set of questionnaires, more than 90% missed grade 1 or 2 periapical changes (according to periapical index scoring), resorption and canal calcification. More than 80% of dentists missed extra roots and root curvature buccally while no dentists were able to interpret the periodontal ligament width changes, lamina dura and canal variation (C-shape). Using a paired *t*-test, there was significant variation in answers between the first set and second set of questionnaires.

Conclusion: It is concluded from this study that general dental practitioners are able to detect radiographic changes when they are extensive but they miss periodontal ligament width and lamina dura changes.

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Introduction

Endodontics is one of the few branches in dentistry in which both diagnosis and treatment depend largely upon radiographs.¹ Success of root canal treatment depends on a number of factors, in particular the diagnosis of the pulp and periapical conditions, root canal anatomy, canal preparation and obturation. Modern endodontic diagnosis relies heavily on radiographic examination and provides the most valuable information compared with other diagnostic tests.^{2,3} A clinician must be trained to identify normal anatomical landmarks and their variations as well as variations owing to pathology in a

radiograph. Radiograph images have all the elusive qualities of a shadow so normal anatomical structures in a radiograph must be known thoroughly before interpreting the abnormalities.⁴ Wuehrmann described an organized method of interpreting an intraoral periapical radiograph,⁵ which involves reviewing one structure at a time. Radiographic examination of the periapical region is important when evaluating periapical status and for the success and failure of root canal treatment.^{6–9} From an intraoral periapical view radiograph, the following radicular findings should be assessed:^{4,10,11}

1. length of root
2. curvature of root both mesial-distal and buccal–lingual curvatures

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Figure 1 Extra root in mandibular first molar

3. some features (if present) that assist in determining the position of the apical foramen
4. periapical radiolucencies
5. lateral radiolucencies, if any
6. periodontal defects, if any
7. number of roots present
8. number of canals present
9. lamina dura continuity, shape and density
10. periodontal ligament shape and width
11. root resorption: external, internal and apical
12. canal calcification
13. fracture of root, if any.

The radiographic evaluation by dentists of the periapical area is reported to be unpredictable and inconsistent with diagnosis of pulpal and bone disease.⁹ This inconsistency is due to wide variation in interpretation among different observers and within the same observers at different times.^{9,12-18} Kaffe et al⁹ suggested providing dentists with better radiographic diagnostic criteria for a more consistent evaluation of radiographs and to find the most important and reliable

Figure 2 Extra root in mandibular pre-molar

Figure 3 Open apex in maxillary central incisor

radiographic features that will enable the clinician to interpret them correctly.

The purpose of this study was to evaluate which radicular radiographic features the general dentists will want to interpret in a pre-operative diagnostic intraoral periapical radiograph for root canal treatment, determine which radicular radiographic features general dentists interpret correctly and which ones they miss in an intraoral diagnostic periapical radiograph and correlate how correctly general dentists are able to interpret radicular radiographic features that they want to interpret for root canal treatment.

Materials and methods

The study included two sets of questionnaires. In the first set of questionnaires, the general dentists were asked which radicular radiographic features they would interpret from a pre-operative diagnostic radiograph for root canal treatment, while the second set of questionnaires consisted of 30 intraoral periapical radiographs that were grouped under 5 categories according to tooth position (Table 1):

1. lower molars—eight radiographs
2. lower premolars—four radiographs
3. upper anteriors—seven radiographs

Figure 4 Grade C calcification (calcific metamorphosis)

- 4. upper molars—six radiographs
- 5. upper premolars—five radiographs.

In each radiograph the tooth to be assessed was identified and given to the general dental practitioners for their assessment and interpretation of radicular radiographic features. The 30 intraoral diagnostic radiographs that were used in this study were selected randomly from the patients who had undergone root

Figure 5 Grade C root curvature in distal direction

Figure 6 Grade C root curvature in buccal direction

canal treatment at the Department of Conservative Dentistry and Endodontics, CSI College of Dental Sciences, Madurai, India. The criteria for the selection of radiographs were that they should have good clarity, no cone cut and root apex and the surrounding structures should be adequately visible.

The 30 radiographs selected for this study were viewed and analysed by 3 experienced endodontists to record the various radicular findings and derive at gold standard findings. The radicular findings analysed were (Table 1):

- 1. number of roots (Figures 1 and 2)
- 2. open apex (Figure 3)
- 3. canal calcification, graded A, B or C according to the American Association of Endodontics (AAE) case difficulty assessment form (Figure 4)¹¹
- 4. root curvature, graded A, B or C according AAE case difficulty assessment form (Figures 5 and 6)¹¹
- 5. presence of root resorption (Figure 7)

Figure 7 Apical one-third root resorption

Figure 8 Grade A periodontal ligament widening

6. periodontal ligament width (PDL) widening graded A, B or C according to Agnar Halse et al's classification (Figures 8–10)¹⁹
7. whether the lamina dura is broken or incontinous (Figure 11)
8. periapical bony trabeculae changes graded 1, 2, 3, 4 or 5 according to periapical index scoring (PAI) by Orstavik et al.²⁰

Figure 9 Grade B periodontal ligament widening

Figure 10 Grade C periodontal ligament widening

For any radiograph where there was disagreement in the findings among the three endodontists, and the findings were finalized after a consensus following joint discussion.

The radiographs used in this study were taken using an X-Mind® AC X-ray generator (Satelec Acteon Group, Gustave Eiffel, France) operated at 70 kVp and 8 mA. Size 2 periapical Kodak dental films (Eastman Kodak Co., Rochester, NY) were used. Periapical radiographs were taken using paralleling cone technique and films

Figure 11 Lamina dura incontinuity

Table 1 Distribution of radiographs given to general dentists with radicular findings agreed upon by three independent endodontists

<i>Position of tooth</i>	<i>Radiograph nos.</i>	<i>No. of roots (radiograph nos.)</i>	<i>Open apex (radiograph nos.)</i>	<i>Canal calcification^a (radiograph nos.)</i>	<i>Root curvature^b (radiograph nos.)</i>	<i>Root resorption (radiograph nos.)</i>	<i>PDL width widening^c (radiograph nos.)</i>	<i>Lamina dura broken/continuous (radiograph nos.)</i>	<i>Bony trabeculae changes^d (radiograph nos.)</i>
Lower molar	8 (1,2,4,5,6,7,8)	Regular 2 roots 4 – (2,6,7,8) Extra root 2 – (4,5) C-shaped 2 – (1,3)	–	Grade A 4 – (2,3,7,8) Grade B 4 – (1,4,5,6)	Grade A 8 – (1,2,3,4,5,6,7,8)	2 – (2,6)	Grade A 1 – (3) Grade B 3 – (1,4,5) Grade C 4 – (2,6,7,8)	7 – (1,2,4,5,6,7,8)	Grade 1 3 – (3,4,5) Grade 2 1 – (1) Grade 3 3 – (2,6,7) Grade 5 1 – (8)
Lower premolar	4 (9,10,11,12)	Regular 1 root 2 – (11,12) Extra roots 2 – (9,10)	–	Grade B 4 – (9,10,11,12)	Grade A 4 – (9,10,11,12)	–	Grade B 1 – (12) Grade C 3 – (9,10,11)	4 – (9,10,11,12)	Grade 1 1 – (12) Grade 3 3 – (9,10,11)
Upper anterior	7 (13,14,15,16, 17,18,19)	Regular 1 root 7 – (13,14,15,16, 17,18,19)	2 – (13,18)	Grade A 3 – (13,15,18) Grade B 3 – (14,17,19) Grade C 1 – (16)	Grade A 7 – (13,14,15,16, 17,18,19)	1 – (18)	Grade B 3 – (13,15,16) Grade C 4 – (14,17,18,19)	7 – (13,14,15, 16,17,8,19)	Grade 1 3 – (13,15,16) Grade 3 2 – (18,19) Grade 4 2 – (14,17)
Upper molar	6 (20,21,22,23, 24,25)	Regular 3 root 4 – (20,23,24,25) Fused 3 roots 1 – (21) 2 roots 1 – (22)	–	Grade B 6 – (20,21,22, 23,24,25)	Grade A 5 – (20,21,22,24,25) Grade C 1 – (20)	1 – (25)	Grade A 1 – (20) Grade B 4 – (21,22,23,25) Grade C 1 – (24)	5 – (21,22,23,24,25)	Grade 1 4 – (20,21,22,23) Grade 2 1 – (25) Grade 4 1 – (24)
Upper premolar	5 (26,27,28,29,30)	Regular 1 root 4 – (26,27,29,30) Regular 2 roots 1 – (28)	–	Grade B 5 – (26,27,28,29,30)	Grade A 4 – (27,28,29,30) Grade C 1 – (26)	1 – (28)	Grade B 1 – (26) Grade C 4 – (27,28,29,30)	5 – (26,27, 28,29,30)	Grade 1 1 – (26) Grade 3 2 – 3 (27,28) Grade 4 1 – (29) Grade 5 1 – (30)

PDL, periodontal ligament

^aGrade A, canals visible not reduced in size; Grade B, canals and chamber visible but reduced in size; Grade C, canals not visible¹¹^bGrade A, less than 10°; Grade C, more than 30°¹¹^cGrade A, normal PDL width; Grade B, slight widening of PDL width; Grade C, periapical radiolucency¹⁹^dGrades 1, 2, 3, 4, 5 according to Periapical Bone Index²⁰

were held using film holders. Films were developed using manual X-ray developer and fixer (Eastman Kodak Co.) by the time and temperature method.

A total of 20 randomly selected general dental practitioners were asked to fill out the two sets of questionnaires. The radiographs were examined by the general dentists using a conventional X-ray viewbox and magnifying lens under normal room lighting to simulate the clinical situation.

The number of doctors that assessed various radiographic findings was statistically analysed using percentile analysis and descriptive analysis.²¹ Analysis of variance (ANOVA) test was used to analyse the variation in observation among different groups of radiographs.²¹ Paired *t*-test was used to analyse the variation between the features that the general dentists said they would interpret in a radiograph and the findings they actually interpreted in the radiographs given to them.²¹

Results

Of the 20 general dental practitioners selected for this study, 19 (95%) responded to the questionnaires provided. For the first set of questionnaires given to the practitioners, which asked about the findings they would interpret in a pre-operative diagnostic radiograph, 19 responded that they would be assessing periapical pathology changes in the radiograph; only 2 of those 19 responded that they would be assessing lamina dura changes (Table 2).

Tables 3 to 9 show the number of practitioners who assessed the following radiographic changes:

1. periapical changes
2. canal calcification
3. number of roots
4. open apex
5. root curvature
6. root resorption
7. PDL width and lamina dura changes.

Table 3 illustrates the total percentage of practitioners who assessed the periapical changes in radiographs for different positions of teeth. Approximately 73% to 89% of practitioners detected grade 4 and 5 periapical changes (according to PAI) and grade 3 was assessed by 23% to 68% of practitioners. Table 3 also illustrates that grade 1 and 2 periapical changes were detected by 0% to 10% of practitioners.

Table 4 illustrates the total percentage of practitioners who assessed canal calcification according to position of teeth; grade C calcification of the canal was detected by 100% of practitioners and grade A and B calcification of the canal was detected by approximately 0% to 16% of practitioners.

Table 5 illustrates the number of roots assessed according to teeth position. Regular root numbers for

Table 2 Findings that general dentists said they will interpret in a pre-operative diagnostic radiograph for root canal treatment

Periapical pathology % (n)	Calcification in root canal % (n)	Curvature of root % (n)	No. of root canals % (n)	No. of roots % (n)	Root canal morphology % (n)	Root resorption % (n)	Open apex % (n)	Lamina dura % (n)
100.0 (19)	78.9 (15)	78.9 (15)	57.9 (11)	52.6 (10)	42.1 (8)	42.1 (8)	15.8 (3)	10.5 (2)

n, number of practitioners

Table 3 Bony trabeculae changes or periapical pathology assessment by practitioners according to position of teeth

<i>Radiographs</i>	<i>Total percentage of practitioners who assessed the findings according to PAI score (mean number of practitioners)</i>	<i>Total percentage of practitioners who missed the findings according to PAI score (mean number of practitioners)</i>
Lower molar	Grade 1	Grade 1
	10.5 (2)	89.5 (17)
	Grade 2	Grade 2
	0.0 (0)	100.0 (19)
	Grade 3	Grade 3
Lower premolar	64.9 (12.33)	35.1 (6.66)
	Grade 5	Grade 5
	84.2 (16)	15.8 (3)
	Grade 1	Grade 1
	10.5 (2)	89.5 (17)
Upper anterior	Grade 3	Grade 3
	57.9 (11)	42.1 (8)
	Grade 1	Grade 1
	5.3 (1)	94.7 (18)
	Grade 3	Grade 3
Upper molar	23.7 (4.5)	76.3 (14.5)
	Grade 4	Grade 4
	84.2 (16)	15.8 (3)
	Grade 1	Grade 1
	3.9 (0.75)	96.1 (18.25)
Upper premolar	Grade 2	Grade 2
	5.3 (1)	94.7 (18)
	Grade 4	Grade 4
	73.7 (14)	26.3 (5)
	Grade 1	Grade 1
	10.5 (2)	89.5 (17)
	Grade 3	Grade 3
	68.4 (13)	31.6 (6)
	Grade 4	Grade 4
	84.2 (16)	15.8 (3)
	Grade 5	Grade 5
	89.5 (17)	10.5 (2)

PAI, periapical index scoring

a particular tooth were assessed by 47% to 100% of practitioners, fused upper molar roots were detected by only 31% of practitioners, a C-shaped root was detected

as a fused root by approximately 34%, two-rooted upper second molars were not detected by any practitioners and extra accessory roots were detected by 5% to 31% of practitioners.

Table 6 illustrates that 65% of practitioners detected open apex in upper anterior radiographs.

Table 7 illustrates root curvature assessment and shows that grade A curvature was detected by 100% of practitioners and grade C curvature was detected by 15% to 68% of practitioners.

Table 8 illustrates the root resorption assessment by general dentists according to teeth position. 2% to 10% of practitioners detected apical root resorption changes.

Table 9 illustrates the PDL width changes and lamina dura changes assessed by the practitioners. It shows that no practitioners detected PDL width changes and lamina dura changes.

The ANOVA statistical test shows that there is no significant statistical variation between different groups of radiograph assessment by practitioners, at a confidence level of 95%.

The paired *t*-test analysis shows that there is significant variation between the number of practitioners who stated the radiographic findings they will be interpreting and the number of practitioners who actually interpreted these radiographic findings in the radiograph given to them, at a confidence level of 95%. Radiographic features that were taken for this statistical test were:

1. periapical changes
2. canal calcification
3. root canal morphology
4. root resorption
5. open apex
6. lamina dura
7. root curvature
8. number of roots.

Table 4 Canal calcification assessment according to position of teeth

<i>Radiographs</i>	<i>Total percentage of practitioners who assessed the canal calcification^a findings (mean number of practitioners)</i>	<i>Total percentage of practitioners who missed the canal calcification^a findings (mean)</i>
Lower molar	Grade A	Grade A
	2.6 (0.5)	97.3 (18.5)
	Grade B	Grade B
Lower premolar	5.3 (1)	94.7 (18)
	Grade B	Grade B
	9.2 (1.75)	90.8 (17.25)
Upper anterior	Grade A	Grade A
	0.0 (0)	100.0 (19)
	Grade B	Grade B
	0.0 (0)	100.0 (19)
	Grade C	Grade C
	100.0 (19)	0.0 (0)
Upper molar	Grade B	Grade B
	16.6 (3.16)	83.2 (15.8)
Upper premolar	Grade B	Grade B
	3.2 (0.6)	96.8 (18.4)

^aGrade A, canals visible not reduced in size; Grade B, canals and chamber visible but reduced in size; Grade C, canals not visible¹¹

Table 5 Number of roots assessed by practitioners according to teeth position

<i>Radiographs</i>	<i>Total percentage of practitioners who assessed the findings (mean number of practitioners)</i>	<i>Total percentage of practitioners who missed the findings (mean number of practitioners)</i>
Lower molar	Regular root 98.7 (18.5) Extra roots 5.2 (1) Fused root (C-shaped root) 34.2 (6.5)	Regular root 1.3 (0.25) Extra roots 94.7 (18) Fused root (C-shaped root) 65.8 (12.5)
Lower premolar	Regular root 100.0 (19) Extra roots 31.6 (6)	Regular root 0.0 (0) Extra roots 68.4 (13)
Upper anterior	Regular root 100.0 (19)	0.0 (0)
Upper molar	Regular root (3 roots) 75 (14.25) Fused root 31.6 (6) Two roots 0.0 (19)	Regular root (3 roots) 25 (4.75) Fused root 68.4 (13) Two roots 100.0 (0)
Upper premolar	Regular roots (1 root) 100.0 (19) Regular roots (2 roots) 47.4 (9)	Regular roots 0.0 (0) Regular roots (2 roots) 52.6 (10)

Discussion

Interobserver variation in the interpretation of radiographs in this study is similar to previous studies.^{9,12–18} The results of the present study indicate that general dental practitioners are more able to detect periapical changes and canal calcification changes in radiographs when there were moderate to extensive in nature (Tables 3 and 4), but when these changes were to a milder degree they were more likely to be missed by a practitioner. Periapical changes of grade 4 and 5 (according to PAI) were detected by 14–17 practitioners for all the groups of teeth, whereas grade 1 and 2 periapical changes (according to PAI) were detected only by 1–3 practitioners, and 16–18 practitioners missed the radiographic changes altogether. This is in accordance with the study by Halse et al²² where radiographs with PAI scoring grades 1 and 2 represent borderline and difficult cases with the highest amount of interobserver variation, and a final finding is arrived at by joint discussion and consensus among observers. Detection of the presence of root resorption associated with periapical inflammation (Table 8) was assessed by approximately 0–3 general dentists. However, the radiographs with root resorption changes (radiograph numbers 2, 6, 18, 25, 28) (Table 1) were associated with periapical changes of grade 3 and 4 (according to PAI scoring) and this periapical change was detected by 3–17 practitioners from the radiographs (Table 3).⁴ Three practitioners detected root resorption

in the mandibular first molar radiograph where the distal root was resorbed more than one-third in length and was easily detectable. However, in other radiographs where root resorption was present with less obvious radiographic changes and had an oblique or cupped-out appearance, no more than two doctors were able to detect the root resorption finding.⁴ Periapical radiographs were shown to be a successful diagnostic aid when detecting apical root resorption with an acceptable level of accuracy in various studies.^{23,24} Therefore, failure of practitioners in this study to detect apical root resorption must be because of a lack of diagnostic knowledge.

Canal calcification of milder radiographic changes of grade A and B were missed by more than 83% (15) of practitioners in the present study. Grade C calcification of upper anterior teeth (radiograph number 19) with a diagnosis of calcific metamorphosis was detected by all practitioners, but none of them were able to specify the tooth condition as calcific metamorphosis. Kuyk et al²⁵ in his study showed that the radiographic appearance of the root canal correlated well with the histological diameter of the canal, and this study reiterates the importance of canal calcification interpretation using the radiograph. He also advocates that radiographs showing completely calcified canals do have canals present histologically and radiographs showing visually present canals may be clinically difficult to trace.²⁵

For assessment of root numbers from radiographs, Table 5 show that 13 practitioners missed the fused root

Table 6 Assessment of open apex

<i>Radiograph</i>	<i>Total percentage of doctors who assessed the findings (mean number of doctors)</i>	<i>Total percentage of doctors who missed the findings (mean number of doctors)</i>
Open apex	65.8 (12.5)	34.2 (6.5)

Table 7 Root curvature assessment by practitioners according to teeth position

<i>Radiographs</i>	<i>Total percentile of practitioners who assessed the root curvature^a findings (mean number of practitioners)</i>	<i>Total percentile of practitioners who missed the root curvature^a findings (mean number of practitioners)</i>
Lower molar	Grade A 100 (19)	Grade A 0 (0)
Lower premolar	Grade A 100 (19)	Grade A 0 (0)
Upper anterior	Grade A 100 (19)	Grade A 0 (0)
Upper molar	Grade A 100 (19)	Grade A 0 (0)
Upper premolar	Grade C 68.42 (13)	Grade C 31/57 (6)
	Grade A 100 (19)	Grade A 0 (0)
	Grade C 15.78 (3)	Grade C 84.21(16)

^aGrade A, less than 10°; Grade B, 10°–30°; Grade C, more than 30°¹¹

Table 8 Root resorption assessment by practitioners according to teeth position

<i>Radiographs</i>	<i>Total percentile of practitioners who assessed the root resorption findings (mean number of practitioners)</i>	<i>Total percentile of practitioners who missed the root resorption findings (mean number of practitioners)</i>
Lower molar	7.89 (1.5)	92.10 (17.5)
Lower premolar	10.52 (2)	89.47 (17)
Upper anterior	0 (0)	100 (19)
Upper molar	5.26 (1)	94.73 (18)
Upper premolar	5.26 (1)	94.73 (18)

finding in the upper second molar and that all 19 practitioners missed the 2-rooted finding in the upper second molar. The 3-rooted upper second molar (radiograph number 23) was also missed by all of the practitioners (Table 5), which may be due to the fact that the distobuccal root was hidden behind the shadow of the zygoma process. A 2-rooted upper second premolar (radiograph number 28) was missed by 10 practitioners (Table 5). In 1984, Beatty reported that pre-operative radiographs revealing the multiplicity of roots and root canals of the upper molar can produce a false impression of calcification owing to image superimposition of roots and difficulty in interpretation of radiograph.²⁶ Following this, many other studies and case reports have shown the difficulty in assessing the root and root canal morphology of the upper molar and its variation in root fusion from diagnostic radiographs.^{26–30}

In all these case reports and studies it is shown that root variation in the upper molar can be suspected if

there is any variation from normal root morphology in the diagnostic radiograph, and this can be confirmed during access cavity preparation by identifying the extra root canal orifice or by taking additional radiographs. In accordance with these studies and case reports, many practitioners in this study were not able to detect the normal root morphology and its variation in upper molar radiographs. Apart from this, all regular root numbers in other teeth were detected by 18–19 practitioners. A C-shaped canal in the first molar was missed by 17 practitioners on radiograph number 2 and by 8 practitioners on radiograph number 11, and even the doctors who identified the root morphology identified it as fused root rather than a C-shaped root. Recognition of a C-shaped canal from periapical radiographs can be difficult, as shown in various other studies, and our results showed that the practitioners were unable to detect the presence of a C-shaped canal.^{31,32} Fan et al³³ showed that C-shaped mandibular root canals could be detected on radiographs using features such as fused

Table 9 Periodontal ligament (PDL) width/ lamina dura changes assessment by practitioners according to teeth position

<i>Radiographs</i>	<i>Total percentile of practitioners who assessed the findings (mean number of practitioners)</i>	<i>Total percentile of practitioners who missed the findings (mean number of practitioners)</i>
Lower molar	0 (0)	100 (19)
Lower premolar	0 (0)	100 (19)
Upper anterior	0 (0)	100 (19)
Upper molar	0 (0)	100 (19)
Upper premolar	0 (0)	100 (19)

root, presence of longitudinal groove on the root and the assessment of the coronal, middle and apical third of the root canal. In our study, many practitioners were not able to detect the subtle changes in the calcification of canals and the presence of fused root morphology, which led to their failure to interpret the C-shaped canal from the radiograph.³³

Only two practitioners assessed the extra root presence shown in the lower first molar radiograph (Figure 1) (*radix entomolaris*), in radiographs four and five. Only 5 practitioners detected extra root presence in the lower premolar in radiograph number 9 and 7 practitioners detected it in radiograph number 10.³⁴ Slowey demonstrated how difficult it is to detect the presence of extra roots in a multirooted tooth from a radiograph and, in accordance with his study, only two practitioners detected the presence of extra roots in the mandibular first molar in our study.³⁵ Also, because the *radix entomolaris* is in the same plane as the distal root, a superimposition can occur leading to practitioners' failure to detect extra root presence.³⁶ However, more recent studies have shown that *radix entomolaris* could be successfully detected from a radiograph by analysing the crossing of translucent lines defining the pulpal space and periodontal ligament of the mandibular first molar. A thorough inspection of the radiograph to look for unclear outlines of the distal root contour or root canal can also reveal the presence of hidden *radix entomolaris*.^{36,37} There was a higher number of practitioners who were able to detect extra root presence in lower premolar radiographs than in lower molar radiographs (Figure 2) and this may be owing to the fact that in lower premolars the extra root was in the mesial aspect and was easier to detect, whereas in lower molar radiographs the extra root was present in the lingual aspect and so its presence was more difficult to read because of the superimposing image of the main roots.³⁴ Yoshioka et al (2004)³⁸ showed that, 96% of the time, extra root canals in mandibular pre-molar radiographs were correctly detected by dentist using sudden narrowing of the main canal to judge the root canal multiplicity. In agreement with the result of the study by Yoshioka et al,³⁸ this study shows that a higher number of practitioners failed to detect extra root canal presence in the radiograph given to them, owing to their inability to detect canal calcification changes.

An open apex owing to trauma of the upper anterior teeth was detected by 10 practitioners in radiograph number 13 and by 15 practitioners in radiograph number 18. Only approximately six practitioners missed the finding as this was more straightforward.

For root curvature, grade A root curvature was detected by all 19 practitioners. Grade C curvature in the upper molar radiograph number 20 was detected by 13 practitioners, while in the upper premolar radiograph number 26 it was detected by only 3 practitioners. A higher number of practitioners detected the curvature in the upper first molar radiograph (number 20) because

the curvature was in the mesiodistal direction and so it was easy to detect, but the curvature in radiograph number 26 was in the buccolingual direction, which is difficult to interpret, especially in the maxillary arch. Careful assessment of radiopacity of the root and PDL space will help in the identification of curvature and additional radiographs may also be necessary.^{4,39,40} The dentists in our study failed to analyse the PDL space, which hindered their ability to detect the curvature of premolar root in the buccolingual direction. Chen et al, in a study evaluating the radiographic interpretation of root morphology of the third molar in a periapical radiograph, concluded that root curvature was the most misinterpreted finding from radiographic assessment.⁴¹ In agreement with this study, our results show that curvature in the buccolingual direction of the upper second premolar was missed by 16 practitioners.

PDL width and lamina dura changes were not assessed by any practitioners for any radiograph in the present study. This is in contradiction with a study by Kaffe et al⁹ where PDL width and lamina dura changes were evaluated more consistently than other features and diagnosis of pulp and periapical status based on this finding was more accurate than other radiographic features, suggesting that detection of these findings from the radiograph should be emphasized more. The results of PDL width and lamina dura assessment in this study is in agreement with a recent study by Saunders et al,⁴² where even after reinforcement of the criteria used for radiographic interpretation by the observers, PDL space widening interpretation showed a high amount of interobserver variability. Because no practitioners in the present study analysed the PDL space, it greatly affected their ability to detect extra root presence, number of roots in the upper premolar, root curvature in the buccolingual plane, apical root resorption and periapical changes of grade 1 and 2. For all these radiographic features, a higher number of practitioners missed the findings. Also, by not evaluating the PDL and lamina dura changes, it will be difficult for the dentists to assess the pulpal and periapical status accurately when the tooth is in the initial stages of pulpal and periapical inflammation and it will also make borderline cases difficult.^{9,22}

ANOVA was performed to verify the significance of interobserver variation in detecting various radiographic features among different groups of teeth. There was no significant variation, indicating that practitioners in the present study assessed the radiographic features in all groups of teeth in the same manner and also missed the same number of features in all groups of teeth.

The paired *t*-test was carried out to identify significance in variation between what the practitioners said they would be assessing in a pre-operative diagnostic radiograph and what they actually assessed in the radiographs given to them. It was seen that there was significant variation in what they assessed in the radiographs given to them. This significant variation is

owing to the number of practitioners who missed various radiographic findings, especially in grade 1 and 2 periapical changes, grade A and B canal calcification, extra root presence, fused and two-rooted upper molar, fused root (C-shaped canal) lower molar, root curvature in buccolingual plane, root resorption and lamina dura changes. Table 2 shows that eight practitioners said they will be detecting root canal morphology changes in radiographs, but none of the practitioners were able to detect root canal morphology variation, such as a C-shaped canal, from the radiographs given to them, even though it has been shown that C-shaped canals can be predicted from radiographs.³³ Also in Table 2, 11 practitioners said they will be detecting the number of root canals, but it has been shown that a conventional radiograph has low detection potential for assessing lateral or accessory canals.^{43,44} Dawson et al⁴⁵ hypothesized that diagnosis of periapical lesion is not influenced by diagnostic confidence; dentists who feel confident about diagnosing pathology from radiographs are not necessarily able to correctly diagnose the lesion.⁴⁶ This was proven in a study by Stheeman et al⁴⁷ where a dentist's ability to diagnose a radio-opaque lesion was independent of their diagnostic confidence and their diagnostic ability increased when they were more confident regarding the lesion when confronted with a radiograph. In agreement with these studies, our results show that there was significant variation in what the practitioner said they will be detecting from the radiograph and what they were able to detect from the radiographs provided.

Periapical radiographs are still one of the most important diagnostic tools for endodontic treatment, so a proper evaluation and interpretation of the findings in the radiograph is essential for a successful treatment outcome. The results in this study show that practitioners missed a great deal of findings that have previously been shown to be detectable on a radiograph. Stheeman et al⁴⁷ showed that as the diagnostic confidence of dentists increase there is an increase in diagnostic accuracy from radiograph interpretation, and they suggested that methods should be devised in order to improve the diagnostic confidence.

Reliability of interpretation of dental radiographs may be affected by education, training, the viewing conditions and the examiner's knowledge of the subject. Although solutions have been suggested for improved reading of radiographs, there is very little consensus on different approaches.^{48,49} Joint evaluations and discussions have been emphasized as a valid diagnostic strategy for deciding about cases recorded as being difficult or borderline in periapical status, and this strategy has been shown to increase the chance of

obtaining reliable and valid radiographic data.^{19,50} In a study by Saunders et al⁴² it is shown that overall interobserver agreement greatly improved after training and reinforcement of the criteria used for radiographic interpretation. More recent studies have shown that interobserver agreement and dentists' ability to detect lesions in radiographs improves by using training sessions and reinforcing the criteria used for radiographic diagnosis.^{51,52} Reinforcement and training on criteria used for radiographic diagnosis is the best way to improve the radiographic diagnostic ability of dentists.

The radiographic findings that a large number of practitioners missed were findings with mild to moderate density changes in the radiograph. The radiographic features that more practitioners identified were reproduced in the radiograph with a greater degree of density changes. By identifying these areas of inaccuracies, more emphasis can be placed on these definitions while training practitioners. A further study is planned in this aspect to see how much a practitioner's ability is improved in pre-operative diagnostic radiograph assessment after reinforcement in these areas of weakness.

Conclusion

1. Results from this study show that more practitioners are able to detect radicular radiographic features of periapical pathology of grade 4 and 5 PAI, canal calcification grade C, regular root numbers of the lower molar, premolar and upper anterior, open apex in anterior teeth and root curvature in the mesiodistal plane.
2. More practitioners missed the radicular radiographic findings of periapical changes of grade 1 and 2 PAI, apical external root resorption, canal calcification grade A and B, regular root numbers of the upper premolar and fused, two-rooted upper molar, extra root presence, root canal morphology variation as a C-shaped canal and root curvature in buccolingual plane.
3. No practitioner detected the PDL width changes and lamina dura changes, which affected their ability to detect extra root presence, root curvature in buccolingual plane and periapical changes of grade 1 and 2 PAI.
4. More practitioners were able to detect radiographic features that are reproduced with greater density changes in radiographic film.
5. Reinforcement and training in these areas where practitioners were not able to assess the radiographic findings seems the best solution to improve the diagnostic ability.

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