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HEAD, NECK AND DENTAL RADIOLOGY

Electronic processing of digital panoramic radiography for the detection of apical periodontitis

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Abstract

Introduction This study aimed to evaluate the accuracy of both digital complete and small portion of panoramic radiography (PAN) in the detection of clinically/surgically confirmed asymptomatic apical periodontitis (AP) lesions with and without endodontic treatment.

Methods A total of 480 patients/teeth including 120 AP with and without endodontic treatment, and 120 healthy periapex with and without endodontic treatment were detected via CBCT using the periapical index system. Each diseased and healthy patient underwent PAN first and a CBCT scan within 40 days. All 480 cases were assessed by four different methods, as follows: complete PAN with clinical examination of each tooth available and not available, respectively, and small portion of PAN in which a root with crown and root without crown were displayed, respectively. Periapical index system was also used to assess AP by PAN. Accuracy for both complete and small portion of PAN with respect to CBCT was analyzed.

Results The overall accuracy of the four methods for teeth with endodontic treatment (73.4) was higher than teeth without endodontic treatment (66.6). Accuracy of complete PAN and portion of PAN was 71.3 and 68.7, respectively. As regards teeth without endodontic treatment, accuracy was higher for complete PAN in the upper/lower incisive area and for small portion of PAN in the upper molar area. No difference was found in teeth with endodontic treatment.

Conclusion Complete and small portion of PAN showed greater accuracy in the upper/lower incisive area and upper molar area of untreated teeth, respectively, whereas no difference was found in treated teeth.

Keywords Apical periodontitis · Bone lesion · Cone-beam computed tomography · Diagnostic accuracy · Panoramic radiography · Periapical index

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Introduction

Apical periodontitis (AP) is a periapical bone lesion caused by microorganisms penetrating into the root canal up to the apex [1]. Host defense against the endodontic space infection leads to resorption of the apical bone, which appears on radiographs as radiolucent around the root [2]. AP lesions are infrequently present with clear clinical signs and are almost always identified by incidental findings during routine examinations carried out by periapical radiography and panoramic radiography (PAN) [3]. Unfortunately, these techniques have the typical disadvantages of two-dimensional imaging such as anatomic noise, superimposition, and geometric distortion effect [4]. Therefore, the absence of radiolucency on radiographs fails to ensure a healthy periapex [5, 6]. Since an AP might be present even when it is not radiographically identified, cone-beam computed tomography (CBCT) imaging is currently considered to be the most powerful tool to recognize periapical bone lesions [7–10]. CBCT is only moderately affected by metal artifacts [11–14] and has a high spatial resolution [15] with a relatively low radiation dose compared to multi-slice computed tomography [16, 17]. Nevertheless, it has limited capacity to detect soft tissues [18] and the scan time is long with non-negligible motion artifacts [19–21]. The current guidelines do not justify the routine use of CBCT in endodontic practices for radioprotection reasons [22]. It must be performed only in patients with unclear or contradictory clinical signs/symptoms and when additional information can potentially change the treatment planning or postoperative outcomes [23, 24]. Therefore, knowing the capability of detecting a periapical bone lesion via two-dimensional imaging is crucial.

Several papers that assessed the diagnostic accuracy of PAN in identifying AP lesions employed analog X-ray units [5, 25, 26]. A widespread distribution of digital panoramic X-ray units is currently found both in medical imaging centers and in private dental clinics [27]. Since the breakdown of a picture causes an improvement in the image quality as perceived by the human eye [28, 29], in the analysis of AP lesions it could be beneficial to assess the role of digital panoramic radiographs which, thanks to efficient software systems, enable effortless electronic processes opening the way to new diagnostic methods.

The aim of this retrospective study was to evaluate the diagnostic accuracy of both digital complete and small portion of PAN in the detection of clinically/surgically confirmed asymptomatic AP lesions with and without endodontic treatment.

Materials and methods

Patients

Between November 2011 and December 2017, we enrolled via CBCT imaging 480 patients divided in four groups, as follows: patients with at least one AP in teeth with (120) and without (120) endodontic treatment and patients without periapical bone lesions in teeth with (120) and without (120) endodontic treatment. A tooth was defined as root-treated if it had a radiopaque material in the root canal [30]. The 240 patients with and without AP lesions represented the diseased and healthy groups, respectively. One AP was selected for each member of the diseased group. The patients with endodontic treatment (120 diseased and 120 healthy patients) were 20–83 years old (mean age 62 years, 123 women and 117 men). The patients without endodontic treatment (120 diseased and 120 healthy patients) were 22–84 years old (mean age 57 years, 134 women and 106 men). The clinical queries for CBCT examinations were implant planning, dental extractive planning, maxillary sinusitis, focal bone lesions, endodontic planning, post-traumatic fracture, and osteomyelitis. All the 240 patients without endodontic treatment were the same as a previous study [31], whereas the 240 patients with endodontic treatment were randomly selected by a larger sample from another previous study [32]. Therefore, the patients of this study were not new cases. However, this study was approved by the research ethics committee, and informed written consent was obtained from all patients. Each of the 480 patients underwent a PAN first and a CBCT scan within 40 days of the PAN.

Devices

PAN was performed via the Orthoceph OC200 D (Instrumentarium Dental, Tuusula, Finland). It was a digital panoramic radiograph with a rotation time of 17.6 s, 66 kV, and 4.2–7.5 mA.

CBCT imaging was performed via the NewTom 5G (QR srl, Verona, Italy) equipped with a pulsed pyramidal X-ray beam (360° rotation), a very small focal spot (0.3 mm), and an amorphous silicon flat-panel detector (20×25 cm). The protocols used for imaging, called Hi-Res-Regular and Hi-Res-Enhanced by the producer, lasted 26 and 36 s and comprised 360 and 480 basis image frames, respectively. Furthermore, they had a field of view of 6×6 cm, 8×8 cm or 12×8 cm, 110 kV, and 7.1–15.8 mA. All CBCT volumes were reconstructed with a 0.15-mm isometric voxel size. PAN and CBCT images were displayed on a 20-inch medical monitor with a 3-megapixel Barco display (Barco, Kortrijk, Belgium) and 2048 × 1536 resolution. The software programs originally supplied with the systems were used for image evaluation.

Study design and assessment of AP lesions

The study design followed the method of our two above-mentioned papers on AP lesions [31, 32]. Both AP lesions in teeth with and without endodontic treatment were divided into 60 lesions of the upper arch and 60 lesions of the lower arch. In each arch, 30 small lesions of 2.0–4.5 mm and 30 large lesions of 4.6–7.0 mm were selected. These, in turn, were divided into 3 groups of 10 in the incisor, canine/premolar, and molar areas, respectively. Finally, the lesions affecting the cortical bone were separated from those affecting only the cancellous bone.

In CBCT imaging, the patients with teeth that showed no change in periapical bone structure (healthy periapex) or those clearly had a well-defined periapical radiolucent area (diseased periapex) were included. Therefore, CBCT periapical health status was assessed by means of a dichotomous scale, that is, presence and absence of a bone lesion corresponding to the diseased group and healthy group, respectively. Bone lesions were clinically or surgically confirmed as AP lesions [33, 34]. Surgical procedures used to obtain the specimens included curettage, excision, incision, and enucleation. The clinical diagnoses were made by endodontists and oral/maxillofacial surgeons.

The method used to measure AP lesions on CBCT imaging made the intersection between the sagittal and coronal planes coincide with the longitudinal axis of the tooth in question. The axial plane was automatically oriented perpendicularly to the other two planes. The dimensions of the AP lesions were recorded, taking into account the largest measurement observed in one of the three planes. The possible thin rim of cortical bone bordering the radiolucent lesion was excluded from the measurements.

After the diseased and healthy teeth were chosen on reference standard CBCT scans, the corresponding PAN images were retrieved. AP lesions were assessed via PAN by the periapical index (PAI) system of Ørstavik et al. [35], which is a 5-score scale based on radiographic aspects of the periodontal ligament: (1) normal periapical structures; (2) small changes in bone structure; (3) changes in bone structure with some mineral loss; (4) periodontitis with a well-defined radiolucent area; and (5) severe periodontitis with exacerbating features. A PAI of 2 and 3 and a PAI of 4 and 5 were grouped together. Therefore, the PAI system was divided into 3 scores: PAI 1, PAI 2 to 3, and PAI 4 to 5. PAI 2 to 3 scores, as well as PAI 4 to 5 scores, were included in the AP lesions. (A PAI score ≥ 2 was considered a sign of periapical disease).

All 480 cases (both diseased and healthy patients) were assessed by four different methods:

Method 1: Complete PAN. A PAI score was ascribed to each of the periapical bone lesions, but only one lesion was included for comparison among the other three methods. The non-reported teeth were absent or judged as PAI 1 (healthy periapex). This condition represents the most common occurrence in a diagnostic imaging center.

Method 2: Complete PAN. A PAI score was ascribed only to a specific root of a tooth with known health of the crown. This condition represents the most common occurrence in a dental clinical center, where PAN was carried out after an oral examination and the overall status of the patient's mouth was known.

Method 3: A portion of PAN (cropped PAN). PAN was electronically cut to display only a tooth and surrounding tissues up to 8 mm mesially and distally from the investigated root apex. This was done so that the observers would not be influenced by the overall status of the patient's mouth. A PAI score was ascribed to that specific root.

Method 4: A portion of PAN (cropped PAN). PAN was electronically cut to display only dental roots (no crown should be shown) and surrounding tissues up to 8 mm mesially and distally from the investigated root apex. This was done so that the observers would not be influenced both by the overall status of the patient's mouth and by a possible crown treatment/disease. A PAI score was ascribed to that specific root.

Observers and statistical analysis

Two dental radiologists retrieved and cut the 480 PAN images that they themselves had selected in the previously published papers [31, 32]. Each image (complete PAN and portion of PAN) was independently assessed by three radiologists skilled in dental maxillofacial imaging (33, 20, and 14 years of experience). They too were the same radiologists of the previous papers [31, 32]. Moreover, they were blinded to any information about the patient/tooth selected. The largest (i.e., the most represented) PAN PAI value was taken when the opinion was not unanimous. If the radiologists came to three different conclusions, a discussion was held until they reached a consensus. The PAI values of the portions of PAN with the presence of the only root (method 4) were retrieved from our previous papers [31, 32]. The assessment of the PAN images by the other three methods was carried out with a gap of 3 months from each other.

Sensitivity, specificity, positive predictive value, negative predictive value, and diagnostic accuracy for PAN images with respect to the CBCT reference standard images were calculated for each of the four methods. Moreover, the Cohen kappa value was calculated to assess the agreement between PAN and CBCT imaging. These analyses were fulfilled in the total sample and stratified for size of lesion, anatomical area, and bone resorption type. In the whole sample, the interobserver reliability for the PAN PAI system-categoric variable defined by the three-score scale (PAI 1, PAI 2–3, and PAI 4–5) was also calculated using the Cohen kappa. Kappa values of 0.01–0.20, 0.21–0.40, 0.41–0.60, 0.61–0.80, 0.81–0.99, and 1 represented slight, fair, moderate, substantial, almost perfect, and perfect agreement, respectively. A P value $\leq .05$ was considered to be statistically significant.

In summary, we divided the study into two phases. In the first phase, two dental radiologists retrieved the PAN images corresponding to the standard reference CBCT examinations from our previous papers. They enrolled the 480 patients/teeth via CBCT imaging (120 diseased patients with and without endodontic treatment, and 120 healthy patients with and without endodontic treatment) so that the diseased group had 10 AP lesions for each of the 3 anatomic areas (incisor, canine/premolar, and molar) in both the upper and lower arches and for each of the two sizes of lesions (2–4.5 mm and 4.6–7 mm). This was achieved to have unambiguous subdivisions of the lesions for each area and size. In the second phase, three other radiologists ascribed a PAI score to the PAN images for each of the first three evaluation methods above mentioned. The assessment of PAN images based on the fourth method was retrieved from our previous papers [31, 32].

Results

Both in teeth with and without endodontic treatment, the diagnostic accuracy of the four methods did not show statistically significant differences in the identification of AP lesions based on anatomic area, lesion size, and bone resorption type (lesions affecting exclusively the cancellous bone and those also involving the cortical bone).

For each method, sensitivity, specificity, positive predictive value, negative predictive value, diagnostic accuracy, and kappa values for PAN images with respect to CBCT images were provided in Tables 1, 2, 3, and 4.

The Cohen kappa values showed a moderate or substantial agreement between the three observers for each of the four methods (K value from 0.47 to 0.76), with the exception of the agreement between the observer 2 and observer 3 for the method 2 in the endodontically treated teeth, which was good ($K = 0.83$).

The overall accuracy of the four methods for the teeth with endodontic treatment (73.4) was higher than teeth without endodontic treatment (66.6). Furthermore, the accuracy of complete PAN (methods 1 and 2) and portion of PAN (methods 3 and 4) was 71.3 and 68.7, respectively.

Table 1 Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), diagnostic accuracy, and kappa value for complete panoramic radiography in relation to cone-beam computed tomography imaging, in both untreated tooth and treated tooth

Method 1	Untreated tooth						Treated tooth					
Anatomical area–lesion size–bone resorption type	Sensitivity	Specificity	PPV	NPV	Accuracy	Kappa	Sensitivity	Specificity	PPV	NPV	Accuracy	Kappa
Both arches	37.5	96.7	91.8	60.7	67.1	0.343	54.2	95.8	92.9	67.6	75.0	0.500
Upper arch, incisive area	25.0	95.0	83.3	55.9	60.0	0.200	30.0	95.0	85.7	57.6	62.5	0.250
Upper arch, canine-premolar area	35.0	95.0	87.5	59.4	65.0	0.300	60.0	95.0	92.3	70.4	77.5	0.550
Upper arch, molar area	10.0	95.0	66.7	51.4	52.5	0.500	35.0	90.0	77.8	58.1	62.5	0.250
Lower arch, incisive area	30.0	95.0	85.7	57.6	62.5	0.250	60.0	95.0	92.3	70.4	77.5	0.550
Lower arch, canine-premolar area	60.0	100.0	100.0	71.4	80.0	0.600	80.0	100.0	100.0	83.3	90.0	0.800
Lower arch, molar area	65.0	100.0	100.0	74.1	82.5	0.650	60.0	100.0	100.0	71.4	80.0	0.600
Small lesions (2–4.5 mm)	23.3	96.7	77.8	71.6	72.2	0.242	40.0	95.8	82.8	76.2	77.2	0.411
Large lesions (4.6–7 mm)	51.7	96.7	88.6	80.0	81.7	0.540	68.3	95.8	89.1	85.8	86.7	0.681
Cortical bone	46.5	96.7	83.3	83.5	83.4	0.503	65.1	95.8	84.8	88.5	87.7	0.659
Cancellous bone	32.5	96.7	86.2	69.0	71.6	0.328	48.1	95.8	88.1	74.2	77.2	0.478

Radiologists were not aware of the clinical examination of each tooth. Apical periodontitis was divided by anatomical area, size, and type of bone involvement

Table 2 Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), diagnostic accuracy, and kappa value for complete panoramic radiography in relation to cone-beam computed tomography imaging, in both untreated tooth and treated tooth

Method 2	Untreated tooth						Treated tooth					
Anatomical area–lesion size–bone resorption type	Sensitivity	Specificity	PPV	NPV	Accuracy	Kappa	Sensitivity	Specificity	PPV	NPV	Accuracy	Kappa
Both arches	39.2	96.7	92.2	61.4	67.9	0.358	54.2	95.8	92.9	67.6	75.0	0.500
Upper arch, incisive area	30.0	95.0	85.7	57.6	62.5	0.250	30.0	95.0	85.7	57.6	62.5	0.250
Upper arch, canine-premolar area	35.0	95.0	87.5	59.4	65.0	0.300	65.0	95.0	92.9	73.1	80.0	0.600
Upper arch, molar area	10.0	95.0	66.7	51.4	52.5	0.500	30.0	90.0	75.0	56.3	60.0	0.200
Lower arch, incisive area	30.0	95.0	85.7	57.6	62.5	0.250	60.0	95.0	92.3	70.4	77.5	0.550
Lower arch, canine-premolar area	65.0	100.0	100.0	74.1	82.5	0.650	80.0	100.0	100.0	83.3	90.0	0.800
Lower arch, molar area	65.0	100.0	100.0	74.1	82.5	0.650	60.0	100.0	100.0	71.4	80.0	0.600
Small lesions (2–4.5 mm)	21.7	96.7	76.5	71.2	71.7	0.223	40.0	95.8	82.8	76.2	77.2	0.411
Large lesions (4.6–7 mm)	56.7	96.7	89.5	81.7	83.3	0.587	68.3	95.8	89.1	85.8	86.7	0.681
Cortical bone	46.5	96.7	83.3	83.5	83.4	0.503	62.8	95.8	84.4	87.8	87.1	0.639
Cancellous bone	35.1	96.7	87.1	69.9	72.6	0.355	49.4	95.8	88.4	74.7	77.7	0.491

Radiologists were aware of the clinical examination of each tooth. Apical periodontitis was divided by anatomical area, size, and type of bone involvement

Table 3 Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), diagnostic accuracy, and kappa value for small portions of panoramic radiography in relation to cone-beam computed tomography imaging, in both untreated tooth and treated tooth

Method 3	Untreated tooth						Treated tooth					
Anatomical area–lesion size–bone resorption type	Sensitivity	Specificity	PPV	NPV	Accuracy	Kappa	Sensitivity	Specificity	PPV	NPV	Accuracy	Kappa
Both arches	36.7	95.8	89.8	60.2	66.3	0.325	50.0	94.2	89.6	65.3	72.1	0.422
Upper arch, incisive area	20.0	95.0	80.0	54.3	57.5	0.150	20.0	95.0	80.0	54.3	57.5	0.550
Upper arch, canine-premolar area	35.0	100.0	100.0	60.6	67.5	0.350	60.0	95.0	92.3	70.4	77.5	0.800
Upper arch, molar area	25.0	95.0	83.3	55.9	60.0	0.200	30.0	90.0	75.0	56.3	60.0	0.600
Lower arch, incisive area	20.0	85.0	57.1	51.5	52.5	0.050	55.0	85.0	78.6	65.4	70.0	0.400
Lower arch, canine-premolar area	60.0	100.0	100.0	71.4	80.0	0.600	75.0	100.0	100.0	80.0	87.5	0.750
Lower arch, molar area	60.0	100.0	100.0	71.4	80.0	0.600	60.0	100.0	100.0	71.4	80.0	0.600
Small lesions (2–4.5 mm)	23.3	95.8	73.7	71.4	71.7	0.231	35.0	94.2	75.0	74.3	74.4	0.337
Large lesions (4.6–7 mm)	50.0	95.8	85.7	79.3	80.6	0.512	65.0	94.2	84.8	84.3	84.4	0.628
Cortical bone	51.2	95.8	81.5	84.6	84.0	0.534	65.1	94.2	80.0	88.3	86.5	0.630
Cancellous bone	28.6	95.8	81.5	67.6	69.5	0.276	41.6	94.2	82.1	71.5	73.6	0.392

Only a tooth was displayed on the cropped panoramic radiography. Apical periodontitis was divided by anatomical area, size, and type of bone involvement

Table 4 Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), diagnostic accuracy, and kappa value for small portions of panoramic radiography in relation to cone-beam computed tomography imaging, in both untreated tooth and treated tooth

Method 4	Untreated tooth						Treated tooth					
Anatomical area—lesion size—bone resorption type	Sensitivity	Specificity	PPV	NPV	Accuracy	Kappa	Sensitivity	Specificity	PPV	NPV	Accuracy	Kappa
Both arches	34.2	95.8	89.1	59.3	65.0	0.300	49.2	94.2	89.4	64.9	71.7	0.433
Upper arch, incisive area	15.0	95.0	75.0	52.8	55.0	0.100	25.0	95.0	83.3	55.9	60.0	0.200
Upper arch, canine-premolar area	25.0	95.0	83.3	55.9	60.0	0.200	55.0	95.0	91.7	67.9	75.0	0.500
Upper arch, molar area	20.0	95.0	80.0	54.3	57.5	0.150	30.0	90.0	75.0	56.3	60.0	0.200
Lower arch, incisive area	15.0	85.0	50.0	50.0	50.0	0.050	50.0	85.0	76.9	63.0	67.5	0.350
Lower arch, canine-premolar area	60.0	100.0	100.0	71.4	80.0	0.600	75.0	100.0	100.0	80.0	87.5	0.750
Lower arch, molar area	60.0	100.0	100.0	71.4	80.0	0.600	60.0	100.0	100.0	71.4	80.0	0.600
Small lesions (2–4.5 mm)	20.0	95.8	70.6	70.6	70.6	0.193	31.7	94.2	73.1	73.4	73.3	0.301
Large lesions (4.6–7 mm)	48.3	95.8	85.3	78.8	80.0	0.495	66.7	94.2	85.1	85.0	85.0	0.643
Cortical bone	48.8	95.8	80.8	83.9	83.4	0.512	62.8	94.2	79.4	87.6	85.9	0.611
Cancellous bone	26.0	95.8	80.0	66.9	68.5	0.248	41.6	94.2	82.1	71.5	73.6	0.392

Only a dental root (no crown) was displayed on the cropped panoramic radiography. Apical periodontitis was divided by anatomical area, size, and type of bone involvement

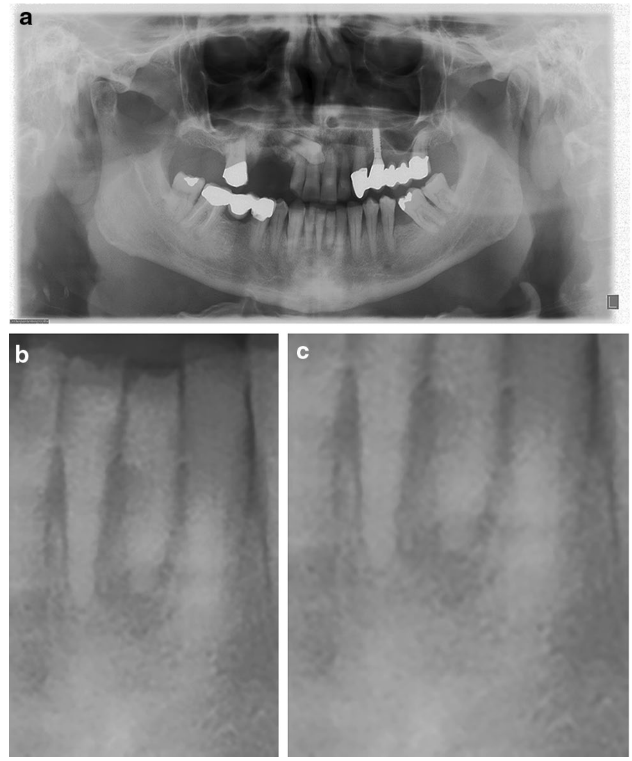

Fig. 1 Anterior lower arch. **a** Complete PAN used for the analysis of the methods 1 and 2, **b** and **c** small portion of PAN used for the analysis of the methods 3 and 4. At the level of the periapex of the lower left lateral incisor, a radiolucent periapical image characterized by supposed changes in bone structure with mineral loss was observed. The complete PAN clearly showed that the radiolucent area had a larger size than the width of the crop area, also involving the periapex of the lower right medial and lateral incisors. Such radiolucent area was not proven to be an apical periodontitis, but it was the projection of the mental fossa

In the upper and lower incisive areas of the teeth without endodontic treatment, the accuracy slightly increased in a gradual manner with values just below the statistical power when from the study of the root only (method 4, accuracy = 52.5) the crown of a specific tooth was observed (method 3, accuracy = 55.0), both dental arches were assessed (method 1, accuracy = 61.2), and the overall status of the patient's mouth was known after an oral examination (method 2, accuracy = 62.5). In the upper molar area of the teeth without endodontic treatment, an opposite trend was found since the accuracy of portion of PAN was higher than complete PAN (accuracy of the methods 3 and 4 = 58.8; accuracy of the methods 1 and 2 = 52.5) (Figs. 1 and 2).

Differences among the four methods were practically inexistent in cases of teeth with endodontic treatment, and in the upper and lower canine/premolar areas and lower molar area of the teeth without endodontic treatment. Regarding the lesion size and bone resorption type, a slightly higher

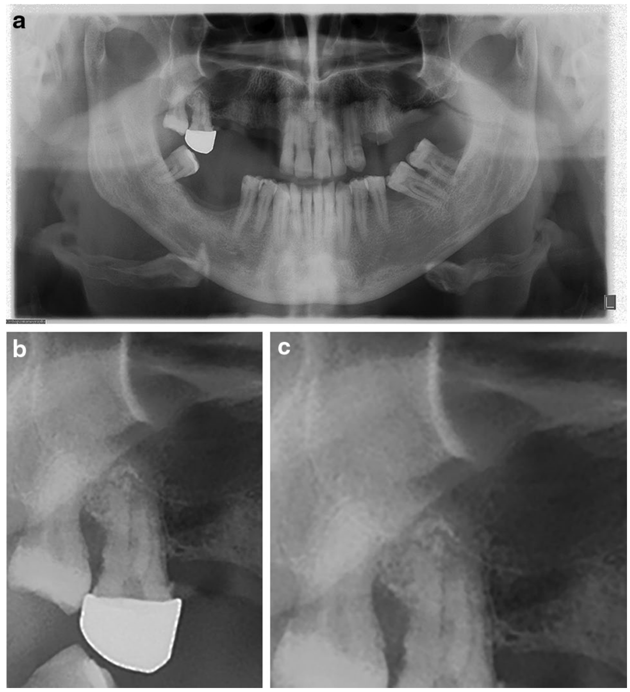

Fig. 2 Posterior upper arch. **a** Complete PAN used for the analysis of the methods 1 and 2, **b** and **c** small portion of PAN used for the analysis of the methods 3 and 4. At the level of the periapex of the upper right second molar, the cropped image placed stronger focus on the rim of cortical bone that bordered the radiolucent periapical periodontitis and that overlapped the radiopaque undulating outline of the maxillary sinus floor

accuracy was observed in the complete PAN than in portion of PAN.

Discussion

The comparison among different evaluation methods of AP lesions did not show statistically significant differences in the diagnostic accuracy both for teeth with endodontic treatment (71.7 to 75.0) and for teeth without endodontic treatment (65.0 to 67.9).

Generally, digital complete PAN was more accurate than portion of PAN, especially in the lower incisive area of teeth without endodontic treatment (62.5 vs. 51.3). The upper molar area of the teeth without endodontic treatment was the only one area in which portion of PAN had a higher accuracy than complete PAN (58.8 vs. 52.5).

The agreement between PAN and CBCT imaging was fair (*K* value 0.30 to 0.36) and moderate (*K* value 0.42 to 0.50) for teeth without and with endodontic treatment, respectively.

The current study aimed to assess AP lesions by entering the clinical reality through potentialities of the digital technology. The methods 1 and 2 simulated what happens in a diagnostic imaging center (no clinician performs the oral examination and no radiologists aware of the clinical examination of each individual tooth) and in a dental clinical center (dentists know the health status of each individual tooth), respectively. The methods 3 and 4 were representations of portions of PAN (cropped PAN) easily achievable by software systems proper to the digital panoramic X-ray units. In the method 3, the representation of crowns could influence the assessment of periapex; the small images simulated periapical radiographies only in size. The method 4 excluded the influence of both the overall status of the patients' mouth and the status of crowns on the assessment of periapex. In each of the four methods, the presence or absence of endodontic treatment was a determining factor for the evaluation of AP lesions, especially for the differences between complete PAN (methods 1 and 2) and small portion PAN (methods 3 and 4). In the analysis of tooth without endodontic treatment, a slight and gradual increase in diagnostic accuracy was observed because of images devoid of external influences (cropped PAN with the only root, method 4, accuracy = 65.0), the visualization of crowns (cropped PAN with both crown and root, method 3, accuracy = 66.3), the overview of the entire mouth (complete PAN, method 1, accuracy = 67.1), and the knowledge of the overall status of the patient's mouth (complete PAN, method 2, accuracy = 67.9). That was mainly noted in the upper and lower incisive areas where the overall view in cropped PAN is lacking with consequent difficulties in isolating AP lesions from anatomic and electronic noises typical of two-dimensional imaging. It was because the projection on the image of structures with obvious morphologic diversities among people, such as nasal bones/cartilages and chin/mental fossa, may have a larger size than the width of the crop area and, consequently, shows such structures beyond the borders of small cropped images. Similarly, plow-dragged artifacts originating from the intrinsic technique unique to the curved rotational tomography during the image formation may extend outside the borders of the crop area. The only one area in which cropped PAN showed a higher accuracy than complete PAN was the upper molar area of the teeth without endodontic treatment. In our opinion, evaluating a limited size area by means of cropping, as is the case in image decomposition [28, 29], helps radiologists and dentists pay more attention to an area difficult to interpret because of its anatomic complexity. The overall view of the maxillary sinus floor with its radiopaque undulating outline around root apexes protruding in the sinus radiolucency was blended into the projection of the periapical lamina dura. AP lesions changed relations between such structures making them difficult to understand. Although it is known that metallic materials produce artifacts [11–14], in teeth with endodontic treatment root fillings marked the pulp canal up to the apex drawing the morphology of the whole root and apical periodontium. This was the main reason why in treated tooth any difference in accuracy among the four methods was found. Nevertheless, a little reduction in the accuracy of the incisive areas and especially the lower incisive area was observed for the same reasons as indicated above about untreated tooth.

In both treated tooth and untreated tooth, anatomical and projective factors were crucial in determining the accuracy of AP lesions in the different areas. The different morphologies of the upper and lower arches caused a lack in the focus on the upper molar area for technical and rotational reasons of the panoramic X-rays unit, with consequent high geometric distortion effect. The air within the maxillary sinus, the numerous roots infrequently orthogonal to the X-ray beam, the irregular morphology of the maxillary sinus floor, and the anterior part of the zygomatic arch superimposed on root apexes, made it difficult to identify AP lesions in the upper molar area and to a lesser extent in the upper canine/premolar area. Also the analysis of the lower and upper incisive areas was difficult because of the variable morphology of chin/mental fossa and superimposition of the hard palate, skull base, nasal bone/cartilage/air, and cervical spine. Both for complete PAN and small portion of PAN, AP lesions in the lower canine/premolar and molar areas were better recognizable since roots were more orthogonal to the X-ray beam, a lower superimposition of the extraoral anatomic structures was found and no nasal/sinusal air was obviously visible.

Since in the upper molar area of the teeth without endodontic treatment cropped PAN showed a higher accuracy than complete PAN, it is recommended for radiologists and clinicians to perform a quick and easy additional process cutting out electronically a portion of digital image as valuable diagnostic aid.

We did not assess the diagnostic accuracy resulting from the combination of complete PAN and portions of PAN. That should further increase the accuracy in identifying AP lesions. It is wrong to maintain that cropped PAN can replace complete PAN or even periapical radiography in the evaluation of AP lesions. Periapical radiography is still the reference technique for the study of a single tooth, although it is not always able to examine periapex of deep roots. Despite the fact that periapical radiography is affected by typical disadvantages of two-dimensional imaging (difficulty in the patient's positioning, morphological variations of the periapical area, bone mineralization, X-ray angulations, and radiographic contrast [36, 37]), it has greater spatial resolution and higher diagnostic accuracy than PAN in identifying AP lesions because of its more detailed delineation of the continuity and shape of the lamina dura [25]. Additional comparisons among periapical radiography and PAN are necessary for continuous technological innovations of the digital age.

The choice of the right examination to be carried out in the detection of AP lesions is complicated by radioprotection reasons. Periapical radiography and PAN are low dose first-level examinations [38]. Unfortunately, they underestimate AP lesions in general and especially in the upper arch and lower incisive area [31–33, 39]. Despite the possibility to use low dose protocols for endodontic patients characterized by low exposure parameters, limited field of views, and half scans, CBCT imaging remains a second-level examination that should be recommended in individual cases and cannot replace PAN and periapical radiography for any suspected periapical bone lesion [40, 41]. Cutting an image out of a PAN does not entail using additional radiation doses, can always be done in digital imaging, and could be also successfully used in bone lesions of a different nature.

The very good accuracy of PAN in recognizing AP lesions in the lower canine/premolar and molar areas can conclude diagnostic procedures in such areas. On the contrary, the low accuracy and NPV in the upper arch and lower incisive area proved that the probability of a true negative diagnosis is low and that more than one-third of AP lesions are missed by PAN. Therefore, in selected cases a diagnostic in-depth analysis by using CBCT is needed.

The analysis of the four methods examined in the current study proved that the knowledge of the patient's oral status influenced the radiologic diagnosis of a healthy/diseased periapex. Therefore, it is crucial for radiologists to obtain access to detailed clinical reports. Because of poor reproducibility of PAN [37], in the follow-up for AP lesions it is recommended that examinations are performed by the same medical and technical staffs to ensure standardization of the execution method. In addition, digital storages of images enable both to perform complementary simple electronic processing and avoid damaging re-exposure in case examinations are no longer found.

The hypothesis put forward by the authors in their previous study [31] for the lack of a clear agreement between the observers on the effects of electronically cut PAN was not confirmed in the current study since the agreement was also substantial in the assessment of complete PAN. Furthermore, the results of the current study performed on digital PAN confirmed what had been proved by a previous paper [25] that had used analog PAN in which large interobserver variations were found. Therefore, clinicians should carefully judge the results of both complete and cropped PAN by taking its low reproducibility and a high probability of missed diagnosis into account.

A limitation of our study was represented by the enrollment of only periapical bone lesions with sizes between 2 and 7 mm. We did not investigate the diagnostic accuracy of both complete and cropped PAN in not uncommon bone lesions less than 2 mm and especially more than 7 mm; in our opinion, it should increase the false negatives and true positives, respectively. One more weakness was to gather AP lesions in only three anatomic areas for each arch, in particular to gather canines with premolars because of the obvious different morphology and local anatomy. We hope that further work will analyze AP for each individually studied tooth.

Furthermore, we suggest further work that compares direct digital periapical radiography, direct digital PAN (complete and cropped PAN), and CBCT in both non-periapical and non-inflammatory lytic jaws periapical bone lesions. Digital imaging enabled various functions and processing, such as enlargement, white/black inversion, and coloring that could help to identify AP lesions.

Such applications were not investigated in the current study and could be the subject of additional analysis.

Conclusions

In our series, both digital complete and small portion of PAN showed high specificity, low sensitivity, and good diagnostic accuracy in the detection of AP lesions with and without endodontic treatment. Complete and small portion of PAN had greater accuracy in the upper/lower incisive area and upper molar area of untreated teeth, respectively, whereas no difference was found in treated teeth.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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