TECHNICAL REPORT

A suggested technique for the application of the cone beam computed tomography periapical index

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Objectives: Cone beam CT (CBCT) produces undistorted three-dimensional (3D) images of the maxillofacial region with a radiation dosage lower than conventional CT. The periapical index score (PAI) is commonly used to follow up the lesions in the bone using periapical radiographs. Recently, a new PAI based on CBCT was introduced (CBCT-PAI). The aim of this technical report is to present a modified reproducible method to assess the CBCT-PAI.

Methods: CBCT was used to evaluate a periapical bone lesion observed in the area of tooth number 13 before treatment and 2 years after treatment. The modified CBCT-PAI was applied to both the examinations to measure the lesion. The dimensional analysis of the lesion was performed in each plane, assessing three fixed and reproducible dimensions: mesiodistal (M-D), buccolingual (B-L) and coronoapical (C-A). The images were evaluated by three mutually independent examiners. Data were collected and reported in a chart. The results were compared with each other and with the PAI score from the periapical radiographs.

Results: The three observers reported the same measurements of the lesion for each plane. The CBCT-PAI follow-up showed a reduction of the size of the lesion (5D vs 4D) but also an increase in the erosion of the buccal cortical plate. The comparison of CBCT-PAI with classic PAI showed the first method to be more precise.

Conclusions: This technical report shows how the CBCT-PAI can be applied to the CBCT exam of a periapical lesion in a reproducible way.

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Introduction

The criteria to evaluate the success and failure of root canal treatment show significant variability.¹ Clinical and radiographic examinations are the most common procedures used to determine the outcome of root canal therapy.^{2–4} The periapical index score (PAI) system relies on the comparison of periapical radiographs with a set of five radiographic images derived from Brynolf's histological–radiographic correlation study.^{5,6} It represents a healthy periapex (Score 1), the widening of the periodontal ligament (Score 2) and the progressive changes in mineral content of the periapical bone, the development of the periapical lesion (Score 3), the classic appearance

of apical periodontitis (Score 4) and its trend to expansion (Score 5). Radiographs are assessed independently in a “blind” manner by assigning a score according to which of the five reference images the radiograph appears to match.⁵ Among the limitations of this method, we should consider the following: (a) the PAI is based on radiographic and histological findings in the periapical region of maxillary incisors. The validity of using the PAI for all teeth, therefore, might be questionable as the thickness of the cortical bone and the position of the root tips in relation with the cortex varies with the position of the tooth. (b) Conventional radiographs used for the management of endodontic problems yield limited information because of the two-dimensional (2D) nature of the images produced, geometric distortion and anatomical noise. These factors often act in combination.⁷

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Cone beam CT (CBCT) has been designed to produce undistorted three-dimensional (3D) images of the maxillofacial skeleton, including the teeth and their surrounding tissues, with a significantly lower effective radiation dose compared with conventional CT.^{8–10} Apical periodontitis can be detected sooner and more predictably by using CBCT than by using periapical radiographs.^{11–14}

Furthermore, the size and the position of periapical lesions with respect to important anatomical landmarks can be assessed.^{15,16} The CBCT units reconstruct the projection data to provide inter-relational images in three orthogonal planes (axial, sagittal and coronal). In addition, because reconstruction of CBCT data is performed natively using a personal computer, data can be reorientated in their true spatial relationships. Owing to the isotropic nature of the constructed volume elements (voxels), image data can be sectioned non-orthogonally.

Most software applications provide various non-axial 2D images in multiplanar reformation (MPR). Such MPR modes include oblique, curved planar reformation (providing “simulated” distortion-free panoramic images) and serial transplanar reformation (providing cross-sections) which can be used to highlight specific anatomical regions for diverse diagnostic tasks.¹⁷ Enhancements including zoom magnification, window/level adjustments and text or arrow annotation can be applied. With an application framework of the software, it is possible to digitally reconstruct a conventional periapical radiograph that provides a reproducible assessment of periapical lesions and aids in a better understanding of its characteristics.¹⁸ Furthermore, on-screen measurements are free from distortion and magnification.^{19–22}

In 2008, Estrela *et al*¹⁴ introduced a new PAI based on CBCT (CBCT-PAI). The CBCT-PAI was developed from the measurements of periapical lesions interpreted on a total of 1014 images (CBCT scans and periapical radiographs) from 596 patients. These lesions were measured by using the working tools of a software application on CBCT scans in three different dimensions: bucco-palatal, mesiodistal and diagonal. The final CBCT-PAI was attributed based on the largest measurement observed in a given lesion in one of the planes selected. A 6-point (0–5) scoring system was defined as follows:

- Score 0 = intact periapical structures;
- Score 1 = periapical radiolucency with the major diameter of 0.5 mm–1.0 mm;
- Score 2 = periapical radiolucency with the major diameter of 1 mm–2 mm;
- Score 3 = periapical radiolucency with the major diameter of 2 mm–4 mm;
- Score 4 = periapical radiolucency with the major diameter of 4 mm–8 mm; and
- Score 5 = major diameter >8 mm.

Two more variables were added to the system: E = expansion of cortical bone and D = destruction of cortical bone. The limits of this work appear to be:

- (a) the measurements of the lesions are taken by orientating the three orthogonal planes in an arbitrary way and this does not permit measurement of the size of a lesion in repeatable way; and
- (b) the larger “diagonal” diameter of the lesion is chosen without using fixed parameters.

Since the consistency of assessing a cone beam volumetric tomography (CBVT) image can be significantly improved when structured observer and calibration strategies are applied, the aims of this technical report are:

1. to present a method to assess the CBCT-PAI, addressing parameters that are accurate and reproducible, using the follow-up of a clinical case; and
2. to compare the results obtained using this system with those obtained using the conventional PAI recorded from the periapical radiographs.

Figure 1 Periapical radiograph of tooth number 13 showing a periapical radiolucent area with a periapical index score of 5

Technical report

Clinical story

A 52-year-old Caucasian female patient with a non-contributory medical history was referred to the Department of Conservative Dentistry and Endodontics of the University of Cagliari, Italy, for the endodontic evaluation of her maxillary left premolar (number 13). The patient reported recent occurrence of swelling and pain. Extra-oral examination was unremarkable. Intra-oral assessment revealed the presence of a gold–ceramic crown on the tooth and a fistula on the buccal area. There was no pain on palpation and there was a soft tenderness on percussion; probing depth did not exceed 2 mm. The periapical radiograph revealed the presence of a root canal treatment in tooth number 13 and a well-defined periapical radiolucent area: the lesion was given a PAI of 5 (Figure 1). The diagnosis was chronic apical

periodontitis; the root canals were retreated and a surgical procedure was performed to remove and analyse the lesion. A CBVT was then performed to evaluate the lesion and its relationships with the adjacent structures. The CBCT-PAI score was 5+D (Figure 2). Clinical controls were done at 7 days, 6 months and 12 months; the patient was symptom-free and at 6 months the sinus tract was closed. 24 months after treatment the patient was still asymptomatic but a sinus tract was observed in the buccal mucosa and a probing depth of 11 mm was measured on the mesiobuccal side of the root. The periapical radiograph showed a PAI of 2 (Figure 3). A new CBCT was then performed to evaluate the periapical status. The diagnosis was apical periodontitis and possible radicular fracture; the CBCT-PAI was 4+D (Figure 4). The tooth was extracted and a longitudinal fracture was noticed which confirmed the diagnosis.

Figure 2 Pre-treatment cone beam CT examination showing the lesion on tooth number 13 orientated in the three planes, clockwise: coronal plane; sagittal plane; three-dimensional reconstruction; and axial plane. The lesion is measured as described in the text in the coronal (coronal plane) diameter; buccolingual diameter (sagittal plane) and mesiodistal diameter (axial plane). Image size: 501 × 501 × 501 pixels, voxel size: 160 µm, 82 kV, 12 mA

Figure 3 Periapical radiograph of the same tooth 2 years after treatment; the sinus tract is traced from the buccal mucosa using a radio-opaque gutta-percha cone. The case is failing again owing to a radicular fracture

CBCT examination

Both the CBCT examinations (Figure 2, Figure 4 and Figure 5) were performed using the Planmeca ProMax 3D (Planmeca Oy, Helsinki, Finland), whose parameters are shown in Table 1. The software used for the case study is the Planmeca Romexis™ Viewer (Planmeca Oy) and the computer was an Intel® Core™ 2 Quad Q8200 2.33 GHz (Fujitsu-Siemens, Munchen, Germany) with 4 GB RAM, NVidia GeForce 9600GT 512 MB (NVIDIA Corporation, Santa Clara, CA) and Windows operating system Vista™ Home SP2 (Microsoft, Redmond, WA). The new CBCT-PAI was applied to the study of this case using a standardized method of exploration. This method was explained to three examiners using 10 CBCT exams of periapical lesions (Cohen's kappa test = 0.88) and consisted of the following steps:

(a) Before the exam, the patient is placed on the machine in a sitting position, the midline is set and the chin positioned in a chin rest to correctly locate the superior-inferior dimension. The volume size, resolution level, kilovolts and milliamps are recorded.

(b) Processing the images:

(1) brightness, contrast and image texture are adjusted through the Romexis Viewer settings for easier navigation and for reducing the intensity of the artefacts.

(2) The lesion is orientated in 3D to make the intersection between the sagittal and coronal planes coincide with the longitudinal axis of the lesioned tooth. The orientation of the three planes (in the following order: axial, sagittal and coronal) is done with "drag and drop" on the 2D projection in each plane to align the object of study with the coloured orientation lines.

(3) Finally, it is possible to measure the lesion by recording its largest diameter for each plane. The coronoapical (C-A) dimension is used instead of the diagonal dimension (as described by Estrela *et al*¹⁴) in order to orientate the lesion for a reproducible follow-up of this case study. The CBCT-PAI is evaluated by examining one plane at a time in order to keep a fixed orientation of the remaining two planes. To determine the largest diameter, the slice scroll-bar is used: through this each plane is examined by 0.16 mm slices and the largest, clearest slice is selected to perform the measurements. Since the orientation has been previously adjusted according to fixed and repeatable benchmarks, during the procedure it is possible to go back to the images previously displayed without losing orientation.

The images were processed and evaluated by the three mutually independent examiners. They measured the largest diameter of the lesion for each plane on the basis of the modified CBCT-PAI. They were also asked to score the periapical radiographs PAI (5, 6). Data were collected and reported in a chart (Table 2).

Results

The observers scored the same periapical radiograph PAI
The three observers reported the same measures of the lesion for each plane of the CBCT.

(1) The comparison of the periapical radiograph taken before the treatment (Figure 1) with the radiograph taken 24 months later shows a considerable reduction of the lesion (from PAI 5 to PAI 2).

(2) The examination of the CBCT before treatment is represented in Figure 2. This image shows the coronal, sagittal and axial planes of the lesion on tooth number 13; the largest measurements obtained were: mesiodistal (M-D) = 8.01 mm, buccolingual (B-L) = 6.75 mm and C-A = 9.12 mm. The erosion of the vestibular plate was observed on the sagittal and axial planes: the M-D measurement of the erosion was 2.24 mm and the C-A measurement (coronal plane) was 2.40 mm. The lesion was classified accordingly as CBCT-PAI = 5+D.

Figure 4 Cone beam CT showing the 2-year follow-up examination of the same area in the same maxillary region corresponding to tooth number 13. The tomographs (coronal, sagittal and axial) show signs of regression of the periapical lesion (the measurements are smaller), yet the lesion is still present. Image size: 501 × 501 × 501 pixels, voxel size: 160 µm, 82 kV, 12 mA

(3) The examination of the CBCT taken 24 months after treatment is represented in Figure 4. The largest measurements obtained were: M-D = 3.85 mm, B-L = 5.04 mm and C-A = 3.84 mm. The erosion of the vestibular cortical plate visible on the sagittal and axial planes measured 3.36 mm on the M-D and 2.72 mm on the C-A plane. The lesion was attributed a CBCT-PAI of 4+D.

(4) The CBCT-PAI shows a reduction in the size of the lesion (5D vs 4D) but it also showed an increase of the erosion of the buccal cortical plate (2.24 mm vs 3.36 mm in the M-D measurement and 2.40 mm vs 2.72 mm in the coronal plane) (Figure 5).

Following treatment, the periapical lesion had not healed but its overall size had decreased and the erosion of the cortical plate had increased in size (Table 2).

Conclusion

The aim of this technical report is to suggest a standardized approach for the application of the CBCT-PAI to the analysis and follow-up of a clinical case, taking into account the existing physical limitations stemming from the differences among different volumetric scanners. In this report, the use of CBCT in conjunction with the CBCT-PAI has provided the initial diagnosis of apical periodontitis, the pre-surgical view of the lesion and the 3D comparison between the first examination and the 2-year follow-up. It has shown the evolution in the size and shape of the lesion (a minimum regression in its overall size and the increased erosion of the cortical plate), indicating the failure of the treatment. The failure was due to the complication of a fracture in the root and the presence of the

Figure 5 Comparison between (a) the cortical plate perforations on the first cone beam CT (CBCT) examination (sagittal and axial planes), and (b) the same views on the 2-year follow-up CBCT. Image size: 501 × 501 × 501 pixels, voxel size: 160 µm, 82 kV, 12 mA

fracture was confirmed after the tooth was extracted. The occurrence of the fracture may explain why there was an initial healing of the bone which resulted in a reduction of the lesion and why the healing process was interrupted and the erosion of the cortical plate had

increased in size. The application of this technique to the follow-up of this clinical case has also shown the difference in the clinically relevant information

Table 1 Technical parameters of Planmeca Promax 3D (Planmeca OY, Helsinki, Finland)

<i>X-ray beam</i>	<i>Cone</i>
Focal spot	0.5 mm, fixed anode
Image detector	CsI coated CMOS flat panel
Greyscale	15 bit
Detector solutions	624 × 624 pixel, dimension pixel 200 micron
Voxel size	160 × 160 × 160 micron isotropic
Image acquisition	300 snapshots in 194° of rotation
Total scan time	18 s, pulsed X-ray
Reconstruction time	< 180 s

CsI, cesium iodide; CMOS, complementary metal-oxide-semiconductor

Table 2 Periapical index score (PAI) obtained with the periapical radiographs. Largest measurements obtained from the coronal, sagittal and axial planes of the cone beam volumetric tomography examination

	<i>First exam</i>	<i>2-year follow-up</i>
M-D lesion meas.	8.01 mm	3.85 mm
B-L lesion meas.	6.75 mm	5.04 mm
C-A lesion meas.	9.12 mm	3.84 mm
C-A breach meas.	2.40 mm	2.72 mm
M-D breach meas.	2.24 mm	3.36 mm
CBCT PAI	5+D	4+D
PAI	5	2

CBCT, cone beam CT; M-D, mesiodistal; C-A, coronapical; PAI, periapical index score; meas., measurement; B-L, buccolingual

gathered with the CBCT-PAI compared with those obtained with the PAI score obtained from the traditional periapical radiographs. The PAI score (5) in this case has shown once more that a false-negative can occur in the follow-up of a radiolucent lesion when 2D radiographs are used. This observation is in agreement with the findings discussed in many different studies in the last 20 years.^{23,24}

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