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Correlation between Mesio-Distal Angulation and Bucco.-Lingual Inclination of First and Second Maxillary Premolars Evaluated with Panoramic Radiography and Cone-Beam Computed Tomography

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Abstract: Background: Panoramic radiography creates distortion in teeth position and inclination especially in lateral areas of the arches due to acquisition and curved shape of dental arch. The aim of this study was to evaluate panoramic distortion compared to cone-beam computed tomography. Methods: Mesiodistal angulations were measured on panoramic radiography. Mesiodistal angulations and buccolingual inclinations of the teeth were determined on cone-beam computed tomography scans. The previous measurements were then compared through Pearson correlation coefficient. Results: The results showed higher correlation between mesiodistal 2D angulation and buccolingual 3D inclination, especially for first premolars, rather than between mesiodistal angulations measured in 2D and 3D. Conclusion: Especially for the lateral areas of the dental arches, root mesiodistal angulation measured on panoramic radiography is not reliable; in fact, it is greatly influenced by buccolingual inclination. Therefore, clinical evaluation is highly recommended with panoramic radiography to provide correct diagnosis and the most satisfactory results.

Keywords: cone-beam computed tomography; panoramic radiography; orthodontic treatment

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1. Introduction

In order to approach predefined cephalometric and occlusal standards, orthodontic treatment has to correct tooth positions in three planes of space [1,2]. Establishing appropriate tooth axial inclinations (mesiodistal and buccolingual) allow for getting root parallelism, which is important to obtain an ideal alignment of the teeth, a normal occlusion, and a stable treatment result, especially in premolar extraction cases. Chiqueto et al. [3] based their investigation on this postulation. Indeed, root parallelism enables the occlusal forces to be distributed through tight interproximal contacts, by the presence of an adequate bone between adjacent teeth [4]. Since the American Board of Orthodontics has recommended a panoramic radiograph to assess parallelism and mesiodistal root inclination, it is currently considered an acceptable aid in clinical practice during diagnosis, treatment planning, and

just before debonding [5–7]. Despite a relatively low radiation dose for patients, its convenience, and a rapid procedure, panoramic radiography has the remarkable disadvantage of providing a radiographic projection produced by a nonparallel beam that gives a distorted and magnified image [8,9]. The parallelism among object and film to one another and the orientation of the X-ray beam at a right angle (90°) is the only way to obtain images consistent with reality [10]. Unluckily, large beam deviations from the perpendicular to the object and the film are necessary to generate a panoramic image, and this creates a geometric distortion in the vertical and horizontal dimensions, and magnification in tooth position and inclination [10], especially in the premolar area [10–16]. Errors are due to the process of image capturing in terms of incorrect focal trough size, shape, and X-ray beam orientation, and also to image processing, which produces ghost imaging, summation images, and static distortion [17,18]. Eventually, head positioning and patient movements affect the panoramic image quality [19]. For all these reasons, panoramic radiography actually does not provide an accurate representation of the true mesiodistal root angulations [19–27]. Indeed, a panoramic radiograph depicts variations of buccolingual inclination as changes in mesiodistal angulation, producing a wrong perception of root parallelism [11,20] because the distortion depends on the position along the object and object depth [27]. One study [20] stated that a lingual root orientation results in apparent increase of mesial root inclination on panoramic radiographies, whereas a buccal root orientation results in an apparent increase of distal root inclination. Another study [12] showed that when the canine has buccal root orientation and the premolar has lingual root orientation, the root mesiodistal parallelism is projected on film as root convergence. Using panoramic radiography to understand correct root parallelism is possible only if the clinician is aware of the amount of distortion and knows how the distortion affects the images. Since it is very difficult, it is recommended to clinically examine teeth alignment just before debonding [20]. Cone-beam computed tomography (CBCT) has recently been suggested as a valid way to assess actual occlusion and root angulations in three planes of space [14,15]. CBCT is also recommended in cases of skeletal malocclusions [28], dental anomalies [29], temporomandibular joint disorders [30,31], evaluation of maxillofacial growth and development [32], anatomical assessment before temporary anchorage devices (TADS) insertion [33], and evaluation of endodontic lesions [34], and it may also be used during orthodontic treatment planning in order to assess tooth inclination and root positions [35]. In order to overcome limits related to radiation levels and optimize radiological risk to diagnostic needs, different Computer Tomography CT and CBCT low-dose protocols have been proposed during the last few years [36,37]. The aim of this retrospective clinical study was to evaluate the reliability of the measurement of the mesiodistal angulation of the first and second premolar on orthopantomographic radiography. For this purpose, a comparative evaluation was made with the measurements of the mesiodistal angulation and the buccolingual inclination of the same dental elements through CBCT images.

2. Materials and Methods

The initial sample of this retrospective study consisted of 45 patients presenting impacted canine in the upper or lower arch, screened from the orthodontic database of University of Insubria (Varese, IT). An informed consent to therapy with a specific release for the disclosure of photographic images and health data for educational–scientific purposes was acquired for each patient. The protocol employed was reviewed and approved by the Ethical Committee, (Approval n° 572); procedures followed adhered to the World Medical Organization Declaration of Helsinki. Among all patients, only those who satisfied inclusion and exclusion criteria were selected for the final group. Inclusion criteria were:

- Presence of panoramic radiography and CBCT of the upper and lower arch, taken no more than three months apart from one another and before the orthodontic treatment when diagnosis of the impacted canine was performed [38];
- First and second upper premolars erupted;

- Good general health (absence of craniofacial syndromes or other craniofacial anomalies).

Exclusion criteria were:

- More than one impacted tooth different from canine;
- Teeth anomalies;
- Low quality of panoramic radiography or CBCT images.

From the initial sample of 45 patients, fifteen patients (mean age 14 ± 0.5 years old; 6 males, 9 females) treated between January 2012 and December 2015 who satisfied inclusion and exclusion criteria were selected. Sample size of at least 9 subjects was necessary to detect a power of 0.8. Sample size was calculated on three subjects on the angular measurements of upper first premolar (difference between means = 1.5 degrees; SD = 1.1 degrees). CBCT acquisition was justified for surgical evaluation of impacted canine, observed at first with panoramic radiography. All of the following measurement procedures on panoramic radiography and CBCT were performed by a single operator. Calibration was performed by two different expert operators to the person who performed the measurements in two different times and double blinded. Then, the main operator, once calibrated, performed the measurements twice with a time interval of one month for all the patients. Therefore, the mean error and 95% confidence intervals (CIs) between the repeated recordings were calculated using the Methods of Moments estimator (MME) variance estimator. The measurement error for angular measurements was 0.9 degrees (range 0.5 and 1.2 degrees). An occlusal plane (PO) was defined on panoramic radiography as a line passing through upper first molar cuspids and upper mesial incisal edge point. Moreover, a dental axis (Axis) was defined as a line from cuspids to apex of upper premolars. The mesiodistal angulation of upper first (U4) and second (U5) premolars was identified by measuring the mesial angle between PO and Axis using ImageJ Software (freeware) on panoramic radiography for left and right sides (Figure 1).

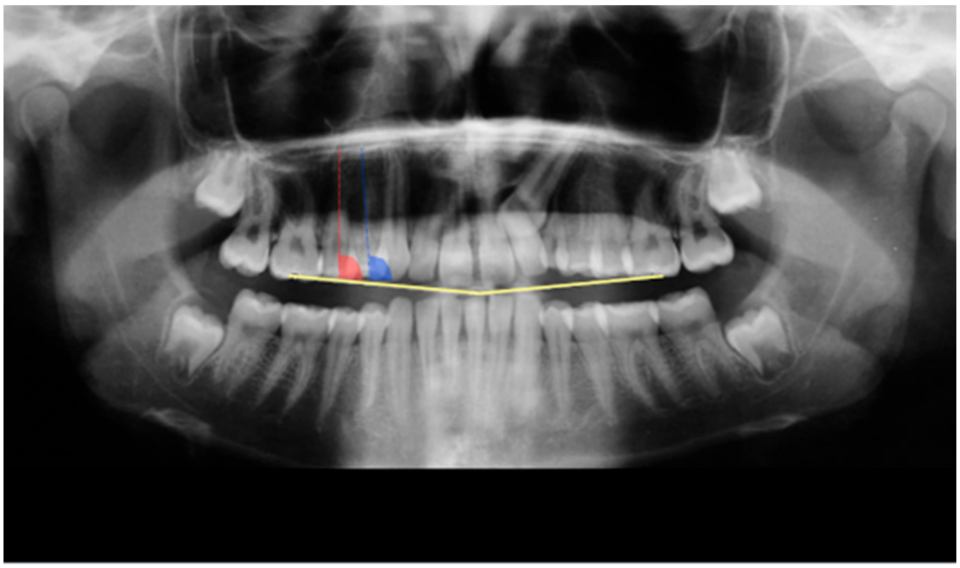

Figure 1. Measurement of mesiodistal angulation on panoramic radiography. The mesiodistal angulation of U4 and U5 was identified by the mesial angle between PO and Axis.

A set of reproducible landmarks (Table 1) was defined for the left and right side and identified using Mimics Software (version 10.11, Materialise Medical Co., Leuven, Belgium) on CBCT in order to measure mesiodistal angulation and buccolingual inclination of maxillary premolars.

The landmarks were exported as Initial Graphics Exchange Specification IGES format to Rhinoceros Software (Robert McNeel and Associates, 3670 Woodland Park Avenue N., Seattle, WA 98103, USA) and buccolingual inclination and mesiodistal angulation

were measured with the Grasshopper® plugin. Grasshopper was chosen because it is a visual programming language that allows for the creation of a digital workflow free from preconstituted software schemes. For each tooth, a proper vertical axis starting from Apex to Facial Axis Clinical Crown (FACC) and a proper horizontal axis starting from FACC to Occlusal were defined (Figure 2).

Table 1. Mimics landmarks. Anatomic points set on cone-beam computed tomography (CBCT) with Mimics Software for both sides.

Landmarks	Definition
U6 Fossa	Central fossa of upper first molars right (R) and (L)
OB	Point of contact of upper with lower incisors
U3 Apex	Apex of upper canine right (R) and (L)
U3 Occlusal	Most anterior and lower point of the pulp chamber of the upper canine right (R) and (L)
U4 Apex	Apex of upper first premolar right (R) and (L)
	(when two roots vestibular root apex)
U4 Occlusal	Most anterior and lower point of the pulp chamber of the upper first premolar right (R) and (L)
U5 Apex	Apex of upper second premolar right (R) and (L)
	(when two roots vestibular root apex)
U5 Occlusal	Most anterior and lower point of the pulp chamber of the upper second premolar right (R) and (L)
U1, U2, U3, U4, U5, U6	Midpoint of Facial Axis Clinical Crown of all the maxillary teeth

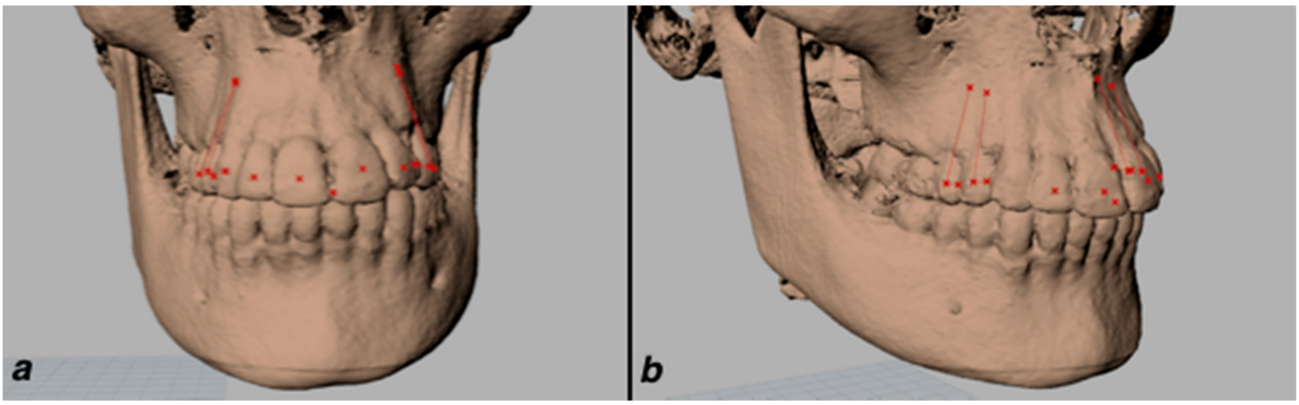

Figure 2. Proper vertical axis and Proper horizontal axis of upper premolars on CBCT. The Proper vertical axis was defined from Apex to Facial Axis Clinical Crown (FACC) and the Proper horizontal axis from FACC to Occlusal Frontal (**a**) and lateral (**b**) view.

Moreover, a FACC plane was built by interpolation of single FACCs of each tooth. Buccolingual inclination was intended to be the angle between the Proper vertical axis and the projection of Proper horizontal axis on FACC plane (Figure 3).

Mesiodistal angulation was intended to be the angle between the Proper vertical axis and the projection of Proper vertical axis on FACC plane (Figure 4).

Sample size calculation and method error analysis:

A sample size of at least nine subjects was necessary to detect a power of 0.8. Eight randomly selected panoramic radiographies and CBCT were retraced by the same operator. No significant mean differences between the two series of records were found by using a paired *t*-test.

Statistical analysis:

SPSS software, version 22.0 (SPSS® Inc., Chicago, IL, USA) was employed to perform the statistical analysis. Parametrical methods were used after having tested the existence through the Shapiro–Wilk test and Levene test of normality of distributions and equality of variance. Mean and standard deviations (SDs) were calculated for each variable tested. Pearson's correlation coefficient *rho* was used to detect a quantitative measure of correlation on a consistent basis between mesiodistal angulation measured on panoramic radiography and mesiodistal angulation and buccolingual inclination measured on CBCT of maxillary left and right first and second premolars. Secondly, a comparison between the variation of mesiodistal angulation measured on panoramic radiography and the variation of mesiodistal angulation and buccolingual inclination measured on CBCT was performed for first and second premolars using regression analysis. The level of significance was set at $p < 0.05$.

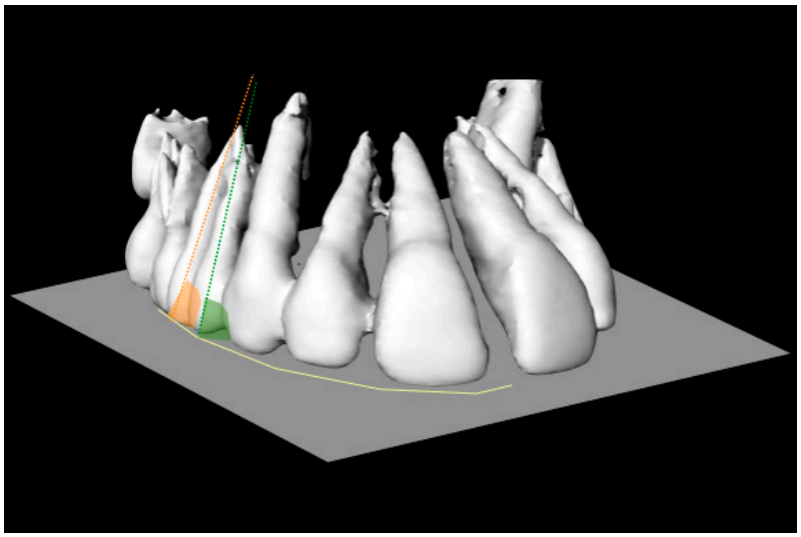

Figure 3. Measurement of buccolingual inclination on CBCT. Buccolingual inclination was identified as the angle between the Proper vertical axis and the projection of Proper horizontal axis on FACC plane.

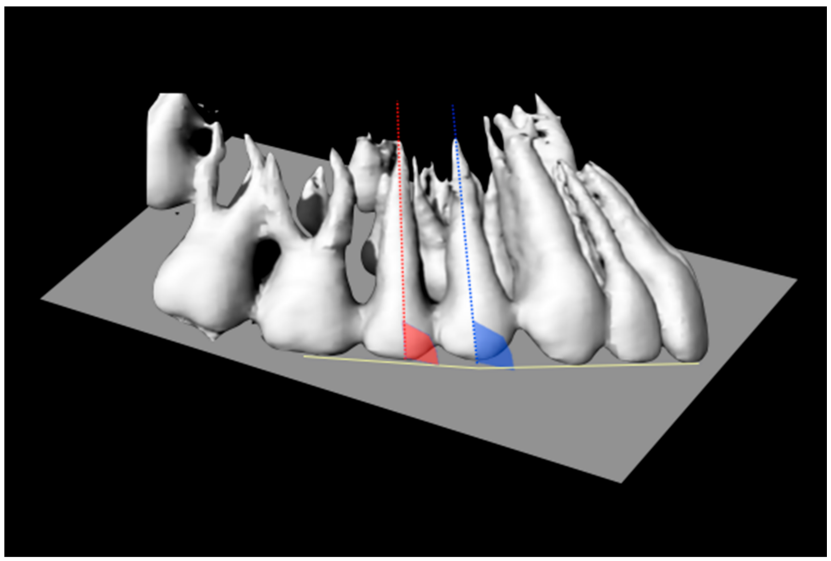

Figure 4. Measurement of mesiodistal inclination on CBCT. Mesiodistal angulation was defined as the angle between the Proper vertical axis and the projection of Proper vertical axis on FACC plane.

3. Results

Data analysis showed a similar linear trend related to panoramic radiography mesiodistal angulation and CBCT buccolingual inclination, concerning upper first premolars. Results of Pearson *rho* correlation analysis are shown in Table 2. Panoramic radiography mesiodistal angulations and CBCT mesiodistal angulations showed low or no correlations for first and second premolars. Medium-high correlations were detected when panoramic radiography mesiodistal angulations were compared with CBCT buccolingual inclinations but only for the first premolars.

Table 2. Results of Pearson *rho* correlation analysis. Low or no correlations are shown among mesiodistal angulation in panoramic radiography and in CBCT for first and second premolars. Medium-high correlations are shown among panoramic radiography mesiodistal (M-D) angulation and CBCT buccolingual (B-L) inclination for the first premolars. Low correlations are shown among mesiodistal angulation in panoramic radiography and both mesiodistal angulation and buccolingual inclination on CBCT for second premolars.

M-D Panoramic Radiography Angulation	CBCT	R Coefficient
U4 right	M-D	−0.46
	B-L	0.70
U4 left	M-D	−0.13
	B-L	0.59
U5 right	M-D	0.18
	B-L	−0.03
U5 left	M-D	0.28

The correlation analysis showed a close link between upper first premolar mesiodistal angulation measured on panoramic radiography and real buccolingual inclination depicted on CBCT. However, there was a low correlation between upper second premolar mesiodistal angulation measured on panoramic radiography and both buccolingual inclination and mesiodistal angulation depicted on CBCT.

4. Discussion

Midtreatment panoramic radiographs are commonly approved in clinical practice to evaluate tooth angulations and then to decide if brackets reposition or detailing bends are necessary. The present clinical retrospective study is based on the assumption made by the previous studies that CBCT is the gold standard in representing mesiodistal tooth angulation. Data from CBCT were compared to data from panoramic RX in order to understand how the latter distorted the mesiodistal angulation of the upper first and second premolars. A comparison between the variation of mesiodistal angulation measured on panoramic radiography and the variation of mesiodistal angulation and buccolingual inclination measured on CBCT was made for first and second premolars. There was a very low correlation between the mesiodistal root angulations shown on panoramic images and mesiodistal root angulations on CBCT for first and second premolars. Medium-high correlations were detected when panoramic radiography mesiodistal angulations were compared with CBCT buccolingual inclinations only for the first premolars. The results showed a similar trend only between the variation of mesiodistal angulation measured on panoramic radiography and the buccolingual inclination measured on CBCT for the first premolar. The correlation analysis showed a consistent correlation between them. No other trends were found, so data of second premolars were excluded from the study. On the basis of these results, it is strictly necessary to add a clinical intraoral evaluation to angulation shown on panoramic radiography in order to guarantee the most satisfactory clinical results.

The present investigation works on the assumption that the canine-premolar is the most distorted region in the upper arch. Many authors have already reported that the representation of the actual mesiodistal root angulation in panoramic radiography is affected by errors. In particular, Samawi and Burke [11] stated that the canine-premolar region of both arches expressed the greatest amount of angular distortion and variability in panoramic radiography. The same results were found by Ann Marie Owens and Ama Johal [13] who showed that in most cases there was a statistically significant difference between the mesiodistal tooth angulations of panoramic images and the actual angle measurement determined on typodont dentition, as shown in the present study comparing panoramic radiography and CBCT. In particular, a panoramic radiograph tends to underestimate incisors and canine angulation and overestimate the angulation of premolar and molar, so posterior roots appear projected more distally than they actually are, with the effect of creating the illusion of exaggerated root divergence between canine and first premolar. This was also proved if panoramic images were compared with CBCT. Another study [12] showed similar results by analyzing images from four panoramic units, which indicated a definite trend in their overestimation and underestimation of the tooth angulations. In this way, possible bias due to a specific panoramic unit was bypassed. The present study avoided these kinds of errors by randomly choosing the panoramic units. In addition, it is necessary to consider the patient's head positioning errors too, because even if there is some tolerance, they affect the mesiodistal tooth angulation on panoramic, as noticed in a study by Mckee et al. [19]. In this study, panoramic images were taken by different technicians and without a standard protocol of use, and it can be considered as a limit of the present investigation; this might have increased the likelihood of patient positioning errors in panoramic radiography. However, it was not possible to do otherwise, as patients had already undergone CBCT and panoramic investigation for individual reasons. Although the acquisition of radiographic examinations performed by different operators may represent a bias of the present study, the use of this material allowed us to conduct a clinical study without exposing patients to further radiation. The acquisition of new radiographic examinations would have been in contrast to the basic principles of radiation protection and would not have been accepted by the ethics committee.

However, we must consider that patient positioning errors are related exclusively to panoramic radiography. CBCT, in fact, ensures a higher accuracy because a specific algorithm corrects the potential distortions generated in the acquisition process, before image reconstruction. According to several studies [14,15,27], CBCT was more reliable than panormaic radiography for root angulation measuring both at the level of maxillary and mandibular arch. Peck et al. [14], after the comparison between model-panoramic radiography and model-CBCT, assumed that CBCT had a significant reliability even in linear and in angular measurements. Eventually this study by Peck et al. comparing panoramic radiography with CBCT, showed not only the same limits of panoramic radiography as other studies [12,13], but also the accuracy of CBCT as the gold standard of diagnostic device in accordance with the present investigation. Assuming CBCT as the gold standard, Bouwens et al. [21] showed a statistically significantly difference (up to 75%) between mesiodistal root angulation measured on panoramic and mesiodistal root angulation measured on CBCT, and they could not identify a reproducible trend of alterations between these imaging devices. In accordance with Bouwens et al., the present study showed a statistically significant difference between mesiodistal root angulation measured on panoramic radiography and mesiodistal root angulation measured on CBCT; furthermore, it identified a relevant correlation between mesiodistal root angulation measured on panoramic radiography and buccolingual root inclination measured on CBCT.

As far as this correlation is concerned, a previous study [11] reported an extensive variability among the effects of a buccolingual inclination on mesiodistal angulation, but it could not identify a standard relationship between them. However, a laboratory investigation by Lee [20] showed that changes in buccolingual inclination predictably affected the appearance of mesiodistal root angulation on panoramic radiography.

On the basis that CBCT is the gold standard, the use of panoramic radiographs to evaluate mesiodistal angulation and buccolingual inclination of first and second maxillary premolars should be approached with caution. A CBCT performed at the end of the treatment would be the finest way for evaluating the root parallelism, but as long as it exposes the patient to a massive radiation dose, then it is not part of standard protocol currently; at most, a CBCT evaluation can be accepted in cases of dental anomalies [39] and bone discrepancies [40] correction, or in cases of orthosurgical procedures [41].

On the basis of the results of this study, in order to obtain an effective assessment of root position at the end of orthodontic treatment, and when it is not possible to perform a CBCT and only a panoramic radiograph is available, it is necessary to carefully integrate radiographic data with intraoral clinical observation.

5. Conclusions

1. Panoramic and CBCT mesiodistal angulations assessment showed low or no correlations for first and second premolars, underlining the limits of panoramic radiography.
2. Medium-high correlations were detected when panoramic radiography mesiodistal angulations were compared with CBCT buccolingual inclinations only for the first premolars; these data highlight the eventuality that on panoramic radiography it is possible to confuse the mesiodistal angulation with the buccolingual inclination of the premolar roots.
3. Root inclination evaluation on panoramic radiography cannot be considered fully satisfactory; therefore, an additional intraoral evaluation is always recommended in order to avoid relevant clinical consequences.

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