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# Methods for Quantitative and Qualitative Evaluation of Alveolar Bone Loss

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Aos meus amigos  que me apoiaram nos momentos mais difíceis mesmo quando o caminho em frente não era claro.

*“Limits like fears, are often just an illusion”*
**Michael Jordan**

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# Abreviations List

| | |
|---|---|
| **CEJ** | **Cement-Enamel Junction** |
| **ER** | Extra-oral Radiograph |
| **IR** | Intra-oral Radiograph |
| **FOV** | Field of View |
| **BD** | Bone Defect |
| **BC** | Bone Crest |
| **CBCT** | Cone Beam Computer Tomography |
| **M-D** | Mesial-Distal |
| **B-L** | Bucco-Lingual |

## Abstract

**Introduction:** Alveolar bone loss results from diverse factors such as periodontal disease or tooth loss. Quantifying alveolar bone loss is important for diagnosis, treatment planning and risk assessment both in periodontal disease and rehabilitation treatments. Qualitative assessment of 3-dimensional aspect of bone destruction is also important for identification of areas that are favorable for regenerative treatments or for early detection and accurate diagnosis of furcation involvement. The direct observation of bone defects can only be done by surgical means which are invasive and so not done in everyday practice. There are various radiographical and clinical complementary means of diagnosis able to indirectly assess hard tissue conditions. It is therefore important to know the advantages and drawbacks of each in order to apply each method for the right clinical situation.

**Aim:** The aim of this study is to review the several surrogate estimators of bone loss available to the clinician in terms of their accuracy, reliability sensitivity and specificity.

**Materials and Methods:** In this review, electronic search was made on PubMed, SciELO and Google Scholar.

**Results**: Orthopantomography was the worst estimator for bone level while CBCT had close to direct measurements. CBCT has shown the best performance in evaluating bone level qualitatively and quantitatively but there is still no proof this leads to a better clinical outcome.

**Conclusion:** Despite being a less accurate and less reliable then the other radiographic methods, its accuracy and reliability are considered sufficient for a rough examination of periodontal status. As for treatment planning the studies in this review suggest CBCT provides the best visualization of bone defect as well as possessing the highest agreement with surgery in the assessment of furcation lesions. However, no proof was found that the use of CBCT improves clinical outcomes of periodontal therapy and thus further studies in order to understand its role in periodontology are needed.

**Keywords:** CBCT; Alveolar bone level; intra-oral radiographs; extra-oral radiographs.

# 1.Introduction

Alveolar bone loss is a chronic condition caused mainly by periodontal disease, which consists of the destruction of the tooth's attachment apparatus in response to specific biofilm species. It has a prevalence of 10-15% in the adult population (1).

Alveolar bone loss assessment is part of diagnosis, prognosis and treatment planning of periodontal disease. Stage of periodontal disease stage is determined by the alveolar bone level. Risk can be determined by considering the bone loss/age ratio allowing us to assess the average yearly destruction. An accurate evaluation of bone level and bone lesion morphology would enhance periodontal diagnosis as well as to assist in treatment plans (2).

Quantifying the remaining bone level as well as 3-D dimensions is also of key importance in implant treatment, in situations where reminiscing bone affects treatment decisions such as immediate implant placing or the need for maxillary sinus elevation (3).

Direct measurement of bone height is performed through open flap surgery. This is an invasive procedure and thus, not done in everyday clinical practice.  To estimate the quantity of bone loss and to qualitatively assess the periodontal defects, there are several estimators available. A surrogate estimate is a variable to measure indirectly a disease or condition, for instance radiological bone loss (or level) is a surrogate estimator of bone loss and surgical measurement of bone loss is an estimator of bone loss (measure directly the bone loss).

This review covers the surrogate estimation of bone loss through radiological means: intra-oral (IR) and extra-oral (ER) radiographs, Cone Beam Computer Tomography (CBCT) and clinically by pocket probing. Since the radiological methods can be costly (CBCT), biologically hazardous (radiation), probing is time consuming and causes some discomfort to the patient it is important to assess the trade-off cost /information (amount and quality) obtained by the referred methods and compare them.

This review will characterize each method regarding is accuracy, reliability, sensitivity and specificity as well as understand what agreement or relation we can expect between them, in order to assist the clinician in choosing the right complementary means of diagnosis for each situation.

## 2.Materials and Methods

This dissertation will take the form of a literature review. PubMed, SciELO and Google Scholar searches were carried out. To perform this, Boolean equations were formulated containing the following keywords:

**Keywords:** CBCT; Alveolar bone level; intra-oral radiographs; extra-oral radiographs.

Clinical cases, meta-analysis, comparative and *ex vivo* studies from the last 30 years (1990-2020) with full text available were included. Only English or Portuguese versions of articles were considered. A significance level of 95% was used as reference.

Initial search results yielded 128 articles. After analysis only 53 articles were included in this study.

# 3.Panoramic Radiograph

Panoramic radiographs have been commercially available for use in dental clinics from the 1960s. Since then, this method became one of the main complementary diagnosis tools available to the dental practitioner. It is a simple, low radiation dose method capable of reproducing the dental arch in a 2D image thus allowing a general perspective of the anatomical structures involved. It is mostly used in the detection of carious lesions of interproximal sites, bone level assessment, tumors located in the maxillomandibular regions and periapical pathology.

## 3.1 Mechanism

The orthopantomography machine includes a horizontal rotating arm carrying an x ray source on one end and a film holder on the other. The x-rays emitted by the x-ray tube suffer different grades of attenuation when passing through the anatomical structures according to the tissue density projecting the 3-dimensional hard tissues in a 2-dimensional film. Several planes are taken and added to make up a composite image where the maxillary and mandibular structures are in the focal plane and the soft tissues that are superficial and deep to this plane are blurred (4).

Over the last 20 years, film-based radiography has been gradual replaced with digital panoramic radiographs which presents a range of advantages including faster image acquisition, elimination of darkroom procedures, maintenance and availability of various digital tools to process the image.

Digital panoramic imaging uses the same principles as its predecessor, with the difference being in the x-ray receptor.

In charge coupled devices (CCD) the film and film holder are replaced by an electronic component made up of light sensitive cells. A scintillator (material that produces light energy when hit by x-rays) is coupled with the detector. As a result, the x-ray energy is converted to light energy just before the detector, and so it is light that excites the sensitive pixels of the detector. This process reduces patient exposure because the presence of the scintillator intensifies the x-ray energy when converting it to light (for each x-ray photon striking the scintillator, several light photons are produced).

The electric charge generated by the cells is processed by a computer that will generate a number according to the charge received. That number is representative of the pixel intensity (in shades of grey) of a specific location in the digital image (5).

## 3.2 Bone level measurement using Panoramic Radiographs

The accuracy of bone level measurement using analogue panoramic radiographs was studied by Åkesson and Pepelassi. In both, bone level estimated by x-rays was compared to surgical measurement through Student t-test. Åkesson concludes ER under-estimates bone loss by an average of 27% in the lower arch to 25 % in the upper arch. Equivalent linear measurements underestimation reached 3mm. Both studies agree that several factors can influence accuracy such as observer, tooth type, location in the dental arch and pocket depth. According to Pepelassi panoramic radiography exhibited the worst sensitivity in detecting initial defects (1 to 2mm), where in the case of severe osseous destruction it tends to overestimate. The weight of each of these factors in affecting measurements is yet to be determined (6) ,(7).

Because, the quality of today's digital panoramic radiographs has now surpassed that of analogue radiographs, due to technical improvements such as laser alignment lights, more accurate movement patterns adjustable according to patient size and jaw form, more consistent focus layer and digital measuring tools, results can differ from analogue to digital radiographs. Recent studies assessing the accuracy of digital panoramic imaging maintain the conclusion that bone loss is on average underestimated in comparison to surgical measurements, although the mean differences seem to be mitigated (8),(9).

## 3.3 Distortion

The distortion of panoramic imaging results from the radiation source being 5°–10° upward from the lingual side. Because of that lingual structures will place higher in the image than buccal structures (10). Furthermore, an ideal angle of the x-ray beam is not always guaranteed due to possible variations in patient position. The inclinations of alveolar processes in  different regions may also play a role (10). This can explain why different degrees of distortion can be found throughout the same radiographic image.

Another determining factor in distortion is the overlapping of anatomical structures due to the 2-dimensional representation of a 3-dimensional object. When a radiographic image is produced by a panoramic machine, objects situated between the central plane of the image layer and the effective rotation center are magnified, while objects located between the central plane and the film are minified. This can become an hinderance when trying to identify key points like the cement-enamel junction and bone crest (11).

Kim Y-K et al, sought to determine the average magnification rate in 86 panoramic radiographs by comparing know implant lengths and widths with their image measurements. Results found a mean enlargement of 27% (12). Statistically different magnifications were found between implant sites at the lower and upper jaws. This agrees with Åkesson who calculated enlargement on over 300 radiographs and found the mean value to be 27% (6).

This can achieve clinical importance in procedures as implant placing at posterior sites where bone height above the mandibular canal is of paramount importance. Schropp L et al, show that using a metal ball to determine magnifying factor affects pre-operative implant size choice by 48%  (13).  Thus, a magnification factor (MF) must be determined before any bone height assessment is made and a safe vertical distance of 2mm to the mandibular canal should be respected to deal with eventual measurements errors.

## 3.4 Reliability and agreement

Hellén-Halme studied digital panoramic linear measurements taken by five observers at mesial and distal sites of teeth 25 and 35. The authors chose these dental sites as they present teeth overlapping and inclination of the alveolar processes. Intra class agreement coefficient result was ICC=0.66 which according to the guidelines established by Koo and Li is considered moderate to acceptable (10). D.Ivanauskaite et al assessed agreement between observers for measurements using the Schei ruler. Agreement was defined as obtaining the same score in the ruler. Kappa values for agreement were k=0.28. Both studies concluded that for initial examination of periodontal status panoramic radiology was a sufficient estimator (14).

### 3.5 Qualitative assessment of hard tissues

Two-dimensional representation immediately presents the disadvantage of not being able to evaluate the lesion in its Bucco-Lingual aspect (B-L). The overlapping of structures can also make distinctions of vestibular and lingual cortical plates impossible. Because of this radiographic assessment of furcation involvement is hampered (2).

Sanja et al, analysed in total, 38 molar teeth with 93 furcation sites scheduled for open flap surgery. All subjects had comprehensive periodontal examination, which included an assessment of molar FI using Naber's probe according to modified Glickman's classification.

Intra surgical measurements were taken and their correlation with panoramic imaging determined. Results showed a poor correlation between both methods (r=0.36) showing panoramic imaging is insufficient in determining furcation involvement. (15)

D.Ivanauskaite et al tested observer agreement for the presence of vertical bone defects and furcation involvement. A total of 1435 and 1446 sites were present for determination of presence or absence of vertical bone defects. For furcation involvement the number of molars was 580. A kappa index of 0.35 and 0.53 were determined for vertical defect and furcation involvement analysis, respectively. It is also important to consider distortion may severely hinder the observer ability to determine any qualitative parameter. One third of the sites were deemed was having unacceptable quality for vertical bone loss assessment (14).

### 3.6 Image processing in panoramic radiographs

Machine learning is one of the core subfields of Artificial Intelligence (AI) that enables a computer model to learn and make predictions by recognizing patterns. The main advantage of machine learning is that the respectively designed AI model is able to improve and learn with experience through increased training based on large and novel image data sets.

The features of alveolar bone resorption and periapical radiolucency can both contribute to the development of AI models for diagnosis of periodontitis and periapical disease.

Krois et al, designed an AI program intended to identify bone loss in panoramic radiography. The program was as trained on 1,456 images and validated on 353 images, respectively. The cut off value for presence of bone loss was 20% (16).

It was then put to test by comparing its assessments with six dentist observers. Mean sensitivity and specificity were 0.81. The mean accuracy of the dentists was 0.76. However, differences between the program and the observers were not statistically significant. It was concluded the program was as effective as trained observers in the detection of periodontal bone loss.

Muramatsu C et al, describes an automated program to detect alveolar bone crests and calculate bone loss in a relative manner. The first step involves transforming the curved image of the dental arch present in a panoramic radiograph to a standardized row of teeth as seen in image Z. This image allows sharper interpretation of pixels by the program in subsequent steps.

Figure 1: Original panoramic radiograph image to be standardized to a row of teeth. Adapted from Muramatsu et al (2016)

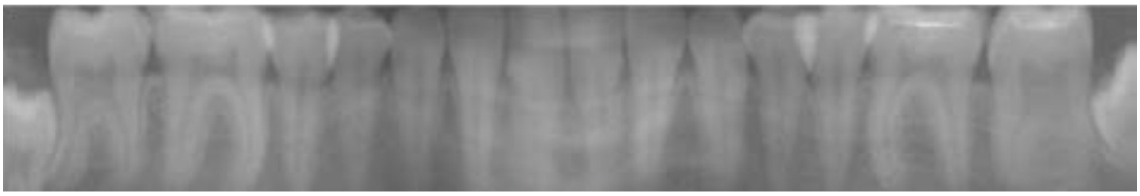

**Figure 2:** Presentation after the standardization algorithm is applied. The teeth no longer present inclinations and it is easier to evaluate the image. Adapted from Muramatsu et al (2016)

Next, for determination of alveolar crest points, a Gaussian smoothing filter is applied to the image. This transform is applied to smooth the image and reduce the noise. The hessian matrix of the image is then calculated. Determination of first and eigenvalues of the matrix allows for a selection of candidate points. Since alveolar crest points can only be situated in the interproximal space any points in the list not belonging to these sites are eliminated. Next a function is used to selected between the candidate points based of a probability estimation that takes in the following parameters : pixel value, gradient strength, gradient direction with respect to the standard direction, θc, and the first and second eigenvalues of the Hessian matrix, respectively.

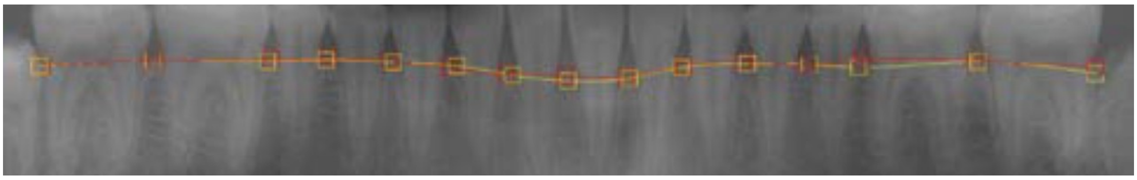

**Figure 3:** Alveolar bone loss represented by the software (yellow line) and by a dentist (red line). Adapted from Muramatsu et al (2016)

The program was then tested against an observer in one case. Results revealed a medium correlation between human and AI. Further developments in this method such as automated CEJ locating can help automate periodontal diagnosis (17).

# 4. Intra oral radiographs

Intra oral radiographs (IR) along with panoramic radiograph are the most common imaging methods used in day to day clinical practice. Bitewing and periapical radiographs allow the clinician to observe a specific area of the dental arch in greater magnification and detail.

The projection geometry of bitewing helps prevent superposition of adjacent proximal surfaces and prevent vertical distortion to some degree. Visualization is best when the sensor is positioned parallel to the long axis of the teeth and the radiograph beam is oriented perpendicular to the sensor. Nevertheless, image magnification can be seen in periapical radiographs and depends on the relative distances of the focal spot-to-film and object-to-film. An average magnification between 1.04 and 1.09 can be expected in intra-oral radiographs recorded with the paralleling technique (6).

## 4.1 Bone level measurement in intra-oral radiographs

As for accuracy studies intra-oral radiology is regarded as close to open surgery measurements. However, there are not consistent results regarding estimation of osseous destruction. Akesson and Pepelassi report analogue IR to be superior to ER in assessing osseous destruction. There is agreement between these authors that periapical radiography is the most accurate method presenting an underestimation between 9 to 20% (95% CI). As with intra-oral radiographs several factors can influence the accuracy of these estimates. When one considers the absolute values of the differences these range from 0.1-1mm. The clinical significance of these should be subject to analysis (6) (7).

Accuracy of IR in measuring bone fill has been considered unacceptable by Grimard. Only 43% of the sites measured within 1mm of the surgical value. On average IR differed from surgical measurements by 0.96mm (+/-1.2, 95% CI) (18). Esmaeli F et al, used Pearson’s r to find a linear relation between surgical measurements taken from 20 periodontal surgery patients and those taken on bitewing radiographs and determined a strong relation coefficient (19).

In deep intrabony defects Li compared not only the depth of the injury (CEJ-BD), but also the width(M-D). While the differences for the width were not significant, intra-oral radiographs, underestimated lesion depth by a mean 0.81mm (20). Other studies by Vandenberghe B et al and Safi et al corroborate these findings (21) (22).

Overall, these studies agree there is an underestimation of lesion depth by periapical and bitewing radiographs. However, values tend to be a good estimate of the gold standard measurement. Intra oral radiographs can be considered a good surrogate method for estimating bone loss.

## 4.2 Reliability

Although most studies show intra-oral radiographs are more accurate than panoramic radiographs the technique involving the first is subject to a lot of different factors that can influence repeatability. Patient compliance can be a problem when posterior sites are concerned as is the presence of mandibular exostoses. X-ray beam manipulation is also subject to the clinician's technique (3) (23).

Wolf B. used bitewing images taken from 50 periodontally compromised patients and applied 2 filters (spreading and structure) as well as 2 degrees of magnification, to understand the factors behind measurement variability. Two previously calibrated examiners assessed the CEJ-BD and the AC-BD distances on the different images. Repeated measures MANOVA was used to determine standard deviations and variances of single radiographic measurements as related to filter, examiner, and magnification. Results show reproducibility of the measurement of the distance CEJ to AC to be significantly influenced by examiner and filter. Differences between observers in observer images varied between 0.35 and 0.62 mm depending on filter (24) .

Hellén-Halme studied how measurements taken at mesial and distal sites of teeth 25, 35 varied between observers. Inter-observer agreement for bitewing's presented significant higher values (ICC=0.85) then those exhibited by ER in this study. According to Koo and Li, this indicates an inter-observer agreement varying between moderate to excellent for measurements in bitewing images (10).

Faria et al, assessed the repeatability of the radiographic technique of parallelism in second mandibular molars after wisdom teeth extraction. For that, 3 periapical radiographs were taken at different times by the same observer and measurements of 2$^{nd}$ molar distal root were made. Results showed no statistical differences between measurements in the 3 radiographs, showing that if the technique is performed correctly, repeatable results can be achieved (23).

## 4.3 Qualitative assessment of hard tissues

IR has reduced distortion levels compared to ER which makes it a more appropriate method for accurate defect visualization. However, other shortcomings of 2-D imaging mainly the overlapping of structures hinder the sensitivity of this test in detecting furcation involvement . Graetz C et al, when comparing observations from IR to surgery, stated that radiographs can only detect 57% of classe 3 furcation lesions and that number is lower for Class 1 and 2 (25).

## 4.4 Standardization of image and software for measurements

Standardization methods have been developed to estimate bone loss in bitewing and periapical radiography as in with panoramic radiography.

The Schei ruler is a plastic transparent ruler with a 1mm thick marking at its margins and 10 equidistant lines radiating from a center point each representing 10% of root length. Using the ruler involves manually identifying Cement-Enamel Junction (CEJ), Marginal Bone level and tooth apex.

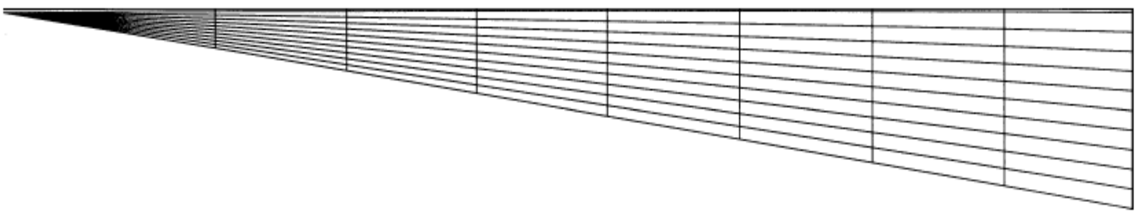

**Figure 4:** Representation of the Schei ruler. Adapted from Teeuw.W. J. et al (2009)

This technique measures bone loss as percentage of the root length which is in accordance with periodontal guidelines for diagnosis. Because the Schei ruler uses teeth as reference for bone level it is not suited to more specific situations such as determining bone height above the mandibular canal in edentulous posterior zones.

Teeuw. W. J et al. developed a digital version of the ruler where the program would receive an input from the user identifying the cement– enamel junction; the position of the alveolar crest along the root; and the radiographic apex.

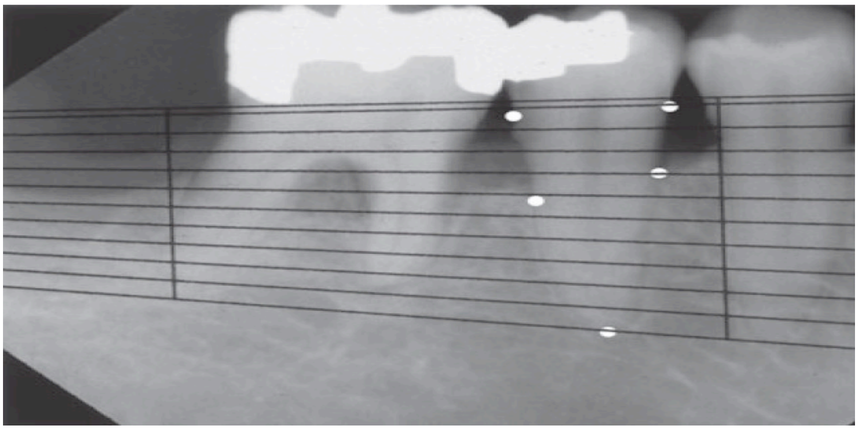

**Figure 5** :Digital version of the Schei ruler. Adapted from Teeuw.W. J. et al (2009)

With this input the software calculates the percentage of bone loss related to percentage of root length. To compare this with the Schei ruler, 40 analogue intra-oral radiographs were digitalized, and measurements were made using the conventional method and software. There were no differences in ICC between the two methods. Both showed high agreement. This method can, therefore, help assessing of bone loss in digital periapical radiographs (26).

Lin et al studied automated methods to identify the alveolar bone crest to help visualize bone defects. Lin traced ROC curves for several estimation methods, each one based on a different parameter. The two best performing methods were intensity, where bone loss is determined by pixel intensity in the interproximal areas of the teeth, and the Fractional Brownian motion (fBm) model, a mathematical algorithm used to determine surface texture through variations of intensity between pixels using the following principles:

$$E(I(x_2, y_2) - I(x_1, y_1)) \propto \left(\sqrt{(x_2, x_1)^2 + (y_2, y_1)^2}\right)^H$$

$$FD = 3 - H$$

Meaning the variation of intensity in a random walk is proportional to the distance travelled elevated to the Hurst coefficient (H). AS the second formula shows the higher the Hurst coefficient the less fractal dimension we get and so less surface roughness.

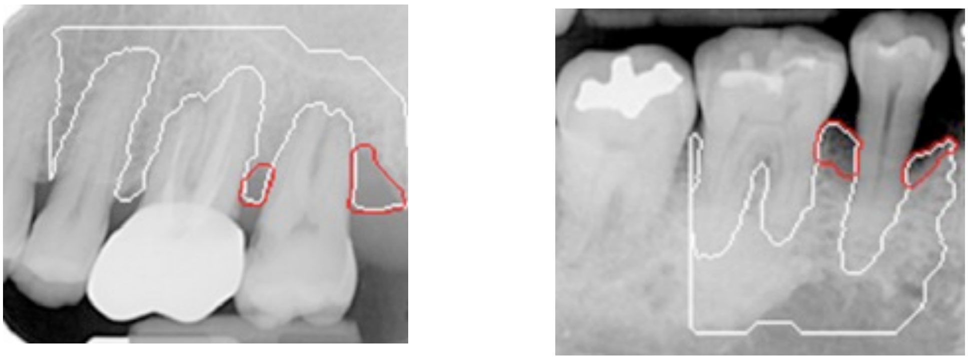

**Figure 6 and 7:** Representation of alveolar bone contours as defined by the software. Adapted from Li et al (2015)

By weighting (determine how each parameter affects the decision) and combining both parameters a program was produced capable of correctly identifying 92.4% of the areas of bone loss in 28 radiographic images. This can have several future applications in clinical visualization of radiographs (27).

# 5.Probing

Probing is the clinical exam that allows the dentist to evaluate the soft and hard tissues surrounding the teeth. It allows the examiner to access information such as clinical attachment loss, presence of inflammation, thickness of soft tissues and sub gingival obstruction. Most of these parameters are valuable diagnostic tools in the case of periodontal disease (28).

Clinical periodontal examination is conducted with a periodontal probe. The probe is an instrument with a thin blunt tip that allows it to enter the gingival sulcus, a space between the teeth and soft tissues. In a healthy mouth the depth of this sulcus ranges from 1 to 3mm. Values above these indicate there is an irreversible loss of collagen fibers that make up the teeth’s attachment apparatus, which eventually leads to irreversible alveolar bone destruction and gingival recession. Therefore, osseous destruction around teeth can be assessed by periodontal probing (29).

## 5.1 Types of probes

There are several types of probes as described by *Pihlström*: manual probes, constant force-controlled pressure probes and constant force automated probes.

The first prototype for a manual probe was invented in 1936 by *Charles H. M. Williams*. Common disadvantages that come with conventional probing are variation in probing force, visual errors in identifying the CEJ, fluctuations in gingival inflammation and misrecording of measurements.

To regulate probing force, pressure sensitive probes were developed by Amitage in 1977 and Van der Velden in 1978 adjusting the pressure the examiner exerts while performing the exam.

Since then electronic automated probes have been upgraded to register missing teeth, recession, bleeding, suppuration, furcation involvement, mobility and plaque assessment. These probes require clinicians to be trained in order to be operated properly. Lack of tactile sensation is also reported.

Studies have been conducted comparing these types of probes. Nitin Gupta et al, observed that *Williams* probes recorded a higher measurement of pocket depth than the electronic probe used in the study, as well as a lower inter observer agreement (30). Antonio Renatus et AL, observed similar measurements when comparing both types of probes but concluded the patient experiences less pain when using an electronic probe which could prove useful for patient compliance and adherence to treatment (31).

## 5.2 Reliability

Probing correctly is very dependent on the clinician ability to correctly interpret and perform measurements. This is supported by Seabra RC et al (32), who compared probing measurements between 3 groups of examiners with different levels of experience (under-graduate students, post graduate students and teachers) in a population of thirty subjects with a diagnosis of chronic periodontitis groups to those made by an electronic probe.

A total of 8,127 periodontal sites were evaluated at the baseline examination and reassessment. Agreement between methods at the baseline examination was (kappa = 0.45) and at reassessment (kappa = 0.42;). The best agreement between electronic and manual probing at the baseline examination was obtained by the postgraduate students (kappa = 0.66) and at reassessment by the associate professors (kappa = 0.60). Undergraduate students obtained the lowest agreement values in both examinations (kappa = 0.42 and 0.11, respectively). No group asserted as being the best but under-graduate students underperformed versus the other subjects showing experience plays a substantial role in this analysis (32).

There are several factors described that can influence the clinician measurement of Clinical Attachment Loss (CAL). *Grossi SG et al* describes factors such as individual patient, probing site, tooth and pocket depth and determines their relative contribution to probing measurement reliability. Pocket depth contributed to 5% of intra-examiner variability, while individual examiner, individual patient and tooth site contributed 10%. The authors concluded a mean variance of 24% or less in intra-examiner reports and attributes the pattern of variance to mostly random errors (33).

A review conducted by *Jerry J. Garnick and Lee Silverstein* describes how periodontal probe diameter affects pocket depth penetration. According to this review if the same force is applied penetration is inversely proportional to the tip diameter. It is concluded that to accurately measure pocket depths a minimum diameter of 0.6mm combined with a force of 20N should be applied (34).

Al Shayeb et al, describe in their review how probe manufacturing process can affect the outcome of the product. Probes from the same production line could differ by over 0.5mm in placement of the etched marking, and the mean tip diameter ranged from 0.28mm to 0.7mm (28).

## 5.3 Qualitative evaluation of periodontal tissues

One of the advantages of periodontal probing when comparing to intra and extra oral radiographs is the assessment of tissue inflammation, if present. According to Consensus report of workgroup 2 of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions, if a clinical sign designated as bleeding on probing exists, it indicates tissue inflammation. This parameter is essential in the diagnosis of periodontal disease (35).

Bleeding and non-bleeding buccal gingival tissues were measured by Souza et al, through manual probing during gingivectomy procedures. The histological evidence of inflammation was used as the gold standard. The histological findings showed statistically significant differences between bleeding and non-bleeding sites (chi2= 20.8). The reliability scores were found to be of high sensitivity (90.9%) as well as of fair specificity (77.3%) (36).

Bleeding on probing reliability can also be affected by force of probing. It has been reported probing pressures reach up to 130g. Furthermore, where probing force exceeds 25g, the gingiva may be traumatized, and further bleeding may occur. Repeated probing may increase the tendency of bleeding although a 15- minutes interval between the initial and subsequent probing may reduce the risk. In addition, a number of systemic diseases, medication and habits such as blood clogging disorders can alter bleeding on probing reading (36).

Tissue inflammation can also have an impact on periodontal probing measurements. Damage to local epithelium and production of cytotoxic substances from certain species of bacteria activate inflammatory cell recruitment processes which lead to vasodilation (37)**.** Clinically this reads as gingival hyperplasia which can lead to false readings of attachment loss as it causes the tissues to migrate coronally. Although a study conducted by *Molina GO et al* show the penetration of the probe is not affected by tissue inflammation, these physiological responses should be considered when measuring attachment loss (38).

In the current paradigm of periodontology Furcation Involvement is usually assessed clinically using a Naber's probe. While its limitations such as tooth position, inclination, presence of adjacent teeth, and variability in operator technique are an impairment to accuracy, 2d imaging presents low sensitivity detecting furcation lesions (39). With the appearance of Cone Beam Computed Tomography some authors have compared the agreement between these methods. Qiao et al, compared both with surgical assessment. The clinical examinations were performed by 2 trained periodontists that underwent calibration. Overall Cohen's Kappa for inter-observer agreement was k=0.729. Complete agreement between clinical examination and surgery observation was only obtained at 21.6% of the sites, compared to 82.4% of the CBCT data. The biggest frequency in agreement occurred at buccal sites (40).

# 6.Cone Beam Computer Tomography

CBCT was introduced in dental practice in the early 2000s. It was introduced in radiology to overcome both the inconveniences that 2D image exhibited as well as the excess in radiation that rendered traditional CT inconvenient in Odontology. In this method imaging is established by rotating an x-ray source and a detector in the same manner as panoramic radiography. A divergent cone shaped x-ray is then produced and directed through the area of interest, with the detector on the opposite site. During the rotation 150 to 600 planar projection images are acquired. Due to the cone like shape of the x-ray beam the entire field of view is captured in a single rotation thus making the process less time consuming (41).

Image reconstruction is performed using algorithms that create a 3d matrix made up of isometric voxels. Each voxel is assigned a number that represents a shade of grey. Voxel size can be adjusted during image acquisition for greater detail at the cost of the presence of noise in the image. The image produced by CBCT has a submillimetre isotropic voxel resolution ranges from 0.4 mm to as low as 0.076mm. Because of this, 3-D reconstruction can achieve levels of spatial resolution which are accurate enough for precise estimates of hard tissues. CBCT also features images represented in the three orthogonal planes thus rendering it useful for not only treatment planning in rehabilitation and periodontology but also orthodontic analyses (42).

CBCT radiation ranges from 5 to 74 times that of a panoramic radiograph (11 to 604 mSv). In normal circumstances radiation is equivalent to a full set of bitewing images. Radiation is larger the bigger the FOV, continuous or discrete x-ray pulsing, volts and amperes and patient position (41).

## 6.1 Accuracy

Performing measurements and observations on CBCT imaging requires knowledge of the software functionalities and well as the adjustable parameters to improve the imaging.

Grimard et al. compared CBCT measurement techniques for assessing bone level changes following regenerative periodontal therapy in 35 intrabony defects. Authors found that overall CBCT was accurate and could be used instead of surgical re-entry(18).

Li et al., conducted pre-surgical measurements of the 3 dimensions of 44 intrabony defects using CBCT. V-L and B-L estimates were not significantly different from direct measurements. However, CBCT was shown to underestimated depth of the intrabony defects (20).

Feijo et al. evaluated the accuracy of CBCT in the detection of horizontal periodontal bone defects. They measured 72 defects in maxillary molar region in patients with periodontitis using CBCT and direct clinical measurement performed during surgical intervention. The authors found that CBCT accurately reproduced the clinical measurement of horizontal periodontal bone defects(43).

To expand upon the sample size of previous studies, Banodkar et al, tested the accuracy in 100 bony defects of both types (80 vertical and 20 horizontal). The authors found CBCT correlates with direct measurements. Correlation was higher in horizontal defects. However, this difference was very small (44).

Unnati Pitale et al. also compared the accuracy of CBCT to open flap surgery measurements in 864 bone loss sites. The mean CBCT value was 4.156 mm and mean surgical value was 4.195 mm. The mean difference was statistically nonsignificant ($p = 0.171$) (45).

## 6.2 Qualitative assessment

The 3D projections of CBCT brought advances in the amount of data one can access. It is the only method capable of estimating B-L dimensions. The comprehensive anatomy of bony defects can help pre-operative planning in such cases as pre-operative membrane synthesis according to the 3d model of CBCT (46).

CBCT had very strong agreement with intra surgical measurements in respect of furcation involvement (40). In a study conducted by Walter J et al, using a sample size of 75 molars, CBCT was compared to intraoperative control. CBCT showed an agreement of 84% with clinical measures. In 14.7% of the cases the intra-operative defects were larger than those measured by the CBCT. Despite enhanced visibility of bony defects and furcation involvement it was not proved CBCT improves clinical outcome (47).

## 7. Agreement and correlation of linear measurements between surrogate estimators

In quantifying alveolar bone loss defining accuracy is important because direct measurements are too invasive for everyday clinical practice. It is also important to assess agreement between methods in order to understand if they provide similar information thereby limiting costs and radiological patient exposure

### 7.1 Intra-oral and Extra-oral radiographs

Gedik et al., studied the accuracy and agreement between the different radiographic methods in images taken at lower mandibular 1st molars. Gedik found no statistical differences between bitewing and panoramic imaging and determined both were accurate in estimating bone loss (8).

Hellen Halme et al., verified the differences between bitewing and panoramic radiographs at upper and lower pre-molar sites. No statistical differences were found for the maxilla and a statistically significant difference of 0.27mm was found for the mandibular PM. The authors used the Pearson coefficient to measure the correlation between both methods. While the maxillary teeth provided a decent correlation (r=0.78) the same could not be verified for the inferior teeth in this study (r=0.55) (10). Gutmacher et al, used radiographies from patients that had gone through implant treatment so calibrate intra and extra-oral radiographs. Measurements from the implant shoulder to the radiographic bone level were made and the differences verified using t-test. No significant differences were found between measurements made in both methods. The authors also found the linear correlation between these methods to be high (48).

### 7.2 Extra oral radiographs and CBCT

Regarding the differences between estimates in panoramic radiographies and CBCT, Oznur Ozalp et al, compared the distance between key anatomical structures in rehabilitation treatment (nasal floor, maxillary sinus, mandibular canal and foramen mentale) and the nearest alveolar crest. Differences were found at all three levels, with the highest mean difference being found at the mandibular canal (0.76mm ,95% CI, 0.533–0.988) (49).  A high correlation was found between panoramic and CBCT imaging in this study (r=0.97).

Shahidi et al, performed a similar test on the distances between edentulous alveolar crest and the mandibular canal. The authors found differences of 0.21mm±0.42mm and concluded that these would not affect pre-surgical planning in routine implant cases(50).

Tang determined correlation coefficients (r) between the paired samples obtained from OPG and CBCT were highly related with r values varying from 0.840 and 0.96 in vertical distances and R values varying from 0.70 and 0.90 in horizontal distances (51).

## 7.3 Intra oral radiographs and CBCT

An in-vitro study by Ritter et al (52) performed a study comparing the histological evidence with CBCT and periapical measurements at implant sites. The author found no significant difference between measurements of measurements of IR and CBCT (p = 0.54) at mesial and distal sites. When Lin compared depths of intrabony lesions no differences were found and both methods showed to underestimate the intra-surgical measurements. Lin hypothesizes that during flap surgery debridement may cause demineralized bone to detach, thus making the defect larger.

## 7.4 Agreement and correlation of furcation involvement between estimators

As radiographic assessment of furcation involvement is deemed unappropriated due to the overlapping of structures and 2-D imaging, this section will focus on probing to CBCT comparisons in furcation involvement.

In Darby et al study, agreement between CBCT and clinical probing was tested. Only 22% of the sites agreed between CBCT and clinical assessment using a probe. In 58% of the sites clinical examination determined a worse condition than that presented on the CBCT (39). Methodology for classifying furcation involvement consisted on quantifying the number of sagittal slices that appeared radiolucent (therefor presenting bone loss) in the furcation area. If more than 10 slices presented radiolucency the lesion would be classified as grade 2 (Hamp classification). If a full visible communication of radiolucencies between mesiopalatal and buccal or distopalatal and buccal entrances was identified the classification would be grade 3.

Qiao et al, who tested the percentage of sites who with the same classification between CBCT, pre-surgical probing and surgical and found only 21.6% were in complete accordance (40). Cimbalijevic used a dichotomous scale (presence or absence) to assess furcation involvement in CBCT but saw only a minor improvement in agreement compared to the previously mentioned studies (46.9%) (53).

# 8.Discussion

In this survey of surrogate bone estimators, we found a significant variability in the experimental design of the selected studies regarding features such as the number and clinical experience of observers, presence or absence of calibration processes and sample size of radiographs.

The number of observers varied between one (7) (20), and five (6). Some were trained periodontists with years of experience (6) (7), radiographers (40), while others were pre- or post-graduate students (39). Calibration of examiners is either present or not specified.

All studies comparing radiographic testing to direct measurements, agree that all radiological methods tend to underestimate bone level (6) (7) (18) (20) (21). Results of Lin et al suggest that debridement may cause reabsorption of demineralized bone at the bottom of the defect increasing the discordance between the two methods (20). We must also consider that direct measurement, despite being considered the gold standard of bone level assessment, is also subject to error factors, such as examiner, presence of granulation tissue and instrument features.

The studies assessing furcation involvement adopted different classification systems making difficult to compare results. Sanja et al used modified Glickman classification (15) while Darby and Qiao et al used the Hamp classification (39) (40), whereas Cimbalijevic uses a dichotomous (presence or absence) scale. However, studies agree that CBCT is the best estimator of furcation involvement in periodontal lesions.

Orthopantomography was shown to be the least accurate estimator of bone level (6), (7). However, studies comparing measurements on panoramic image to CBCT conclude most differences are under 1mm (49),(50),(51) which have minimal clinical significance as diagnosis and treatment planning will not be affected. ER has the lower values for agreement between observers (10), as distortion and overlapping of structures make the identification of anatomical references difficult. All studies assessing accuracy of panoramic imaging considered certain sites unacceptable for performing measurements. Studies also show ER is not suitable to qualitatively assess bone lesions in furcation involvement and to accurately represent anatomic defects (15). These aspects suggest this test is not suited for pre-surgical planning of periodontal treatment. Overall, this review considers panoramic radiography to be the exam of choice for initial evaluation of bone level since its differences from other methods have small or no clinical significance. For the purposes of surgical planning other more accurate methods are indicated. In terms of planning for implant treatment, panoramic radiography should only be used for routine cases and with known distortion (using a calibration object) and only when CBCT is unavailable. In the future with further progress, computer software can be a tool in increasing the reliability of the diagnosis using panoramic radiography.

Intra-oral radiography has advantages, mainly that the paralleling technique allows for imaging with almost no distortion, displaying the structures at its real size (6). Clinically, the technique is not always viable to perform due to patient compliance and presence of mandibular exostoses. Bitewing and periapical radiographs present close to true values of defect depth and seem to show agreement with CBCT in measurements of bone dept defect (20). While it allows us enhanced information regarding defect depth the data regarding defect morphology and furcation involvement is limited due to inherent shortcomings of 2D imaging, and results are inconsistent when different horizontal and vertical angulations are used (2). A full set of bitewings involves 5 times the radiation of an extra-oral radiograph (34.9 to 104.71 mSv). The as Low as Reasonably Achievable (ALARA) fundamental principle for diagnostic radiology should followed when utilizing radiographic methods (3). The information present in this review does not justify the use of intra-oral imaging for periodontal treatment, since a full mouth series involves considerably more radiation and time than ER and the upside of this method does not justify the disadvantages in terms of time and biological hazard. If distortion or human error causes certain sections of ER to be unreadable it is justifiable to perform intra-oral imaging in that area or in the case of sites that y present signs and symptoms of bone lesions.

This review found moderate proof that CBCT is an accurate method and the best qualitative estimator of bone loss and bone defects (18)(45). The 3-dimensional reconstruction proves to be useful in treatment planning of bone defects (regenerative treatment) (30). The precise location of the anatomical structures also makes it a valuable adjunct for complex implant treatment. Due to its high radiation exposure and cost CBCT should be used only in cases where complex rehabilitation and periodontal treatment is concerned. It is important to state that relative to accuracy no definitive proof has been established that places CBCT above other radiological measurements. Further evidence regarding treatment outcomes is necessary to fully establish the role of CBCT in periodontal diagnosis and planning.

# 9.Conclusion

This study concludes that despite only providing a rough estimate of bone loss and being subject to factors that influence observer reliability, extra-oral radiograph is still the imaging method of choice for routine evaluation of bone loss in the maxilla-mandibular complex due to its low radiation exposure and low cost and wide availability. Because it is subject to several encumbrances like the overlapping of structures and variable distortion rates, specific areas in the image may be deemed unacceptable in which case IR is a substitute that overcomes many of the disadvantages of its counterpart. Further developments of software that can help the clinician identify key points in alveolar bone loss can be helpful in the future to strengthen ER reliability.

For accurate measurements of bone loss and qualitative assessment of tissues CBCT shows moderate evidence that it is both accurate and reliable. No sufficient proof was found to state that it is superior to intra oral radiographs in quantifying bone loss although its ability to 3-D visualize structures helps in the detection of furcation lesions and in some reported cases allowed for better treatment performance. However, this review found no evidence that CBCT improves clinical outcomes of periodontal therapy and this should be the focus of future subjects in this study. Regarding implant treatment, as defined by the *Academy of Oral and Maxillofacial Radiology,* CBCT is recommended to obtain imaging of possible implant sites secondary to a panoramic evaluation.

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# Anexos

## Declaração de autorização de publicação

## Declaração de autenticidade do trabalho apresentado

## Parecer do orientador para entrega definitiva do trabalho apresentado

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**DECLARAÇÃO**
Mestrado Integrado em Medicina Dentária

Monografia de Investigação / Relatório de Atividade Clínica

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## Identificação da publicação

**Dissertação de mestrado** ☒

**Título completo** Methods for Quantiative and Qualitative of alveolar Bone Loss

**Orientador** José António Lobo Pereira

**Palavras-chave** Extra-oral radiographs; Intra-oral radiographs; CBCT; Alveolar bone level;

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**Data** 22/05/2020 _

Assinatura João Castro

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**DECLARAÇÃO**

**Monografia de Investigação/ Relatório de Atividade Clínica**

Declaro que o presente trabalho, no âmbito da Monografia de Investigação/Relatório de Atividade Clínica, integrado no Mestrado Integrado em Medicina Dentária, da Faculdade de Medicina Dentária da Universidade do Porto, é da minha autoria e todas as fontes foram devidamente referenciadas.

Porto, 22 de Maio de 2020

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**PARECER DO ORIENTADOR**

**(Entrega do Trabalho Final de Monografia)**

Informo que o Trabalho de Monografia desenvolvido pelo Estudante João Francisco Gomes Ribeiro de Castro, com o título Methods for Quantitative and Qualitative Evaluation of Alveolar Bone Loss está de acordo com as regras estipuladas na FMDUP, foi por mim conferido e encontra-se em condições de ser apresentado em provas públicas.

Porto, 22 de Maio de 2020

O orientador

José António Ferreira Lobo Pereira