



REVIEW ARTICLE

# Using acrylic customized X-ray positioning stents for long-term follow-up studies



Sherif Aly Sadek <sup>a,b,\*</sup>, Hisham Mohamed Abbas <sup>c,d</sup>, Moayad Alfelali <sup>e</sup>, Abdulaziz Almahdali <sup>e</sup>

<sup>a</sup> Department of Prosthodontics, Faculty of Oral and Dental Medicine, Cairo University, Egypt

<sup>b</sup> Department of Prosthodontics, Alfarabi Private College for Dentistry and Nursing, Jeddah, Saudi Arabia

<sup>c</sup> Department of Oral and Maxillofacial Radiology, Faculty of Oral and Dental Medicine, Cairo University, Egypt

<sup>d</sup> Department of Oral and Maxillofacial Radiology, Alfarabi Private College for Dentistry and Nursing, Jeddah, Saudi Arabia

<sup>e</sup> Alfarabi Private College for Dentistry and Nursing, Jeddah, Saudi Arabia

Received 12 June 2019; revised 26 September 2019; accepted 1 October 2019

Available online 15 October 2019

## KEYWORDS

Dental radiovisiography;  
X-ray projection technique;  
X-ray positioning stents

**Abstract** *Objectives:* Long-term assessment of teeth, dental implants, and their corresponding structures is vital to obtain more data concerning the achievement or disappointment of different treatment modalities in clinical situations.

*Aim:* This report aimed to verify the usage of customized X-ray positioning stents suitable for long-term follow-up studies.

*Material and methods:* Two acrylic stents were compared. An X-ray positioning device was built by the incorporation of a bite piece within an acrylic hard nightguard stent and a conventional acrylic film holder were fabricated for 20 patients. Four radiographs were taken of each patient (two of each film holder) at the initial time and after 3 months. Specific linear measurements of the premolar diameter (CEJ width) and the height between the CEJ and the apex were made of all of the radiographs to determine the reproducibility and accuracy of the procedure.

*Results:* The customized X-ray positioning posing stent showed a slight increase in the mean difference of the measurements of the value of the real ratio, demonstrating that the measurements were precise and reliable images of the premolars. The acrylic film holder showed a significant difference in the measurements of the value of the real ratio, indicating unreliable images of the premolars.

*Conclusion:* The device provided reliable linear measurements and produced reproducible images suitable for studies depending on the follow-up analysis.

© 2019 The Authors. Production and hosting by Elsevier B.V. on behalf of King Saud University. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

\* Corresponding author at: 4001 Abu Shujaa Al Asbahani st., Al Safa 8 Dist., Jeddah, Saudi Arabia.

E-mail address: [sherif.sadek@dentistry.cu.edu.eg](mailto:sherif.sadek@dentistry.cu.edu.eg) (S.A. Sadek).

Peer review under responsibility of King Saud University.



Production and hosting by Elsevier

## Contents

1. Introduction	121
2. Materials and methods	122
2.1. Fabrication of customized X-ray positioning stent for group I	122
2.2. Fabrication of acrylic resin stent for group II	122
2.3. Radiographic projection	122
2.4. Radiographic evaluation of tooth height	123
2.4.1. Linear measurements of tooth height	123
2.4.2. Linear measurements of tooth width	124
3. Statistical analysis	124
4. Results	124
4.1. Width results	124
4.2. Height results	125
5. Discussion	125
6. Conclusion	127
Funding	127
Ethical Statement	127
Declaration of Competing Interest	127
References	127

## 1. Introduction

A pivotal tool is needed to provide information related to the failure or success of different therapies in clinical trials for the long-term appraisal of the teeth and dental implants and the structures around them. The foremost non-invasive method for determining the bone level of the implant sites is the radiographic analysis together with the evaluation of the clinical status (Laurell and Lundgren, 2011). Alveolar bone height measurement has precisely demonstrated a linear method of measurement using the periapical paralleling technique from multiple intra-oral radiographic techniques (Wakoh et al., 2006).

Implant dentistry and periodontology necessitates constant observation of patients to identify any transformation in the tissues around the implant. Clinical and radiographic measurements are methods to evaluate peri-implant marginal bone height, although clinical measurements are prone to significant errors because of the non-reproducible projection geometry (Cameron et al., 1998). The diagnosis of the bone height, either bone loss or bone gain from one radiographic inspection to the next, may be very hard to achieve because of mistakes in the alignment of the sequential images. This, combined with intra- and inter-examiner's lack of consistency, causes misunderstanding of the changes in bone density and height and restricts the conventional periapical radiographs' diagnostic value, primarily in cancellous bone (Huh et al., 2005). Updegrave (1951); attempted to solve this problem by introducing a comprehensive technique of a paralleling extension cone. He instituted the Rinn system, which was the first film holder to maintain the parallelism of the film and tooth in a flat position that did not produce favorable images for continued replication to prevent the superimposition of dental radiographs.

To date, many systems have been introduced but have failed to prove their worth. Each system failed to avoid projection errors and were unsuccessful at ensuring the realignment of the initial imaging geometry (Fernández-Formoso et al.,

2011). The most essential feature for the assessment of the bone level is a standardized projection geometry, although in clinical conditions, it does not promise an absolute parallelism between the film plane and the object. Accuracy remains absent, although many systems have been introduced to standardize conventional periapical radiographs (Kuhl and Nummikoski, 2000). Standardization of the geometry and contrast is a requirement for digital subtraction radiography (DSR). To monitor bone changes and small periodontal defects, DSR is better than conventional radiographs as an evaluation method. DSR is more sensitive as it excludes anatomically confusing structures from the radiographic images. Clinically speaking, DSR depends on the standardization of the geometry and contrast to minimize the difference between serially taken radiographic images. According to Dove et al., 2000, the exposure rate and projection alignment should be in the same calibrations when obtaining serially acquired radiographic images for standardization. However, this may be difficult without an appropriate device.

To obtain superimposable radiographs using tomographic and cephalometric techniques, a specially constructed film holder or a commercially available device are used. However, angular variations due to slight misalignment errors or distortion can lead to misinterpretations of bone density changes during subtraction radiography (Dubrez et al., 1995). A fixed position of the focal spot is achieved by the correctly applied film holder, which provides a perpendicular alignment of the central beam toward the film plane. The inclination of the object to the film is the remaining variable during serially taken radiographic images, although the position of the focal spot remains constant. According to Schulze and d'Hoedt (2001); due to the reproduction of 3-dimensional structures (for example, the implant surrounding bone) on a 2-dimensional film image, interpretation mistakes are limited to five projection errors: the oblique position of the objects under examination, image enlargement due to projection magnification, misinterpretation of the margins of the object/sites under examination on the image, and an inaccurate assessment procedure for

distance measurements within the image. Knowledge of imaging geometry is an advantage in calculating the magnification and foreshortening objects that appear in the image. The spatial relationship between the X-ray source, object, and imaging plane in relation to one another during exposure, that is, the projection or imaging geometry, essentially determines the 2-dimensional radiographic image formation. Effects such as these are very common, specifically in dental intra-oral radiography, where anatomical barriers (for example, the hard palate) preclude the parallel positioning of the objects and imaging plane (Schulze et al, 2004).

The DSR imaging technique promotes visualization of changes in the X-ray attenuation properties of tissues. By addressing the increasing need for quantitative measurements of high accuracy, precision, and resolution, DSR attained considerable importance over the last decade. Mol et al. (2003); stated that a high level of standardization in both projection geometry and image density must be achieved to observe changes within the patient against a uniform background of unchanged anatomy. Eickholz et al. (1996); stated that to minimize measurement errors, the projection geometry of serially acquired radiographic images should be standardized. Alveolar bone loss is a dominant component of periodontitis together with clinical findings such as the periodontal pocket formation, marginal inflammation, and attachment loss. Radiographic examination is considered a minimally invasive method for the evaluation of the height of the alveolar bone in comparison to the intra-surgical method, although radiographic evaluation underestimates the amount of bone loss. In successive radiographs, changes to mineralized tissue such as the alveolar bone can be found. Linear measurement can be adopted to evaluate the bone status on a single radiograph in contrast to subtraction analysis, which utilizes at least 2 successive radiographs to evaluate the differences. However, according to Eickholz et al. (1998), projection geometry may have an impact on the validity of interpretation even in a single radiograph.

This study was conducted primarily to achieve standardized serial radiographs by combining the geometric projection standardization and the minimization of distortion of structures such as teeth, implant, and bone to facilitate different types of research. This study was also conducted to determine the reliability of the customized device.

## 2. Materials and methods

Twenty patients aged from 20 to 30 years were selected from the outpatient Clinic of Alfarabi Private College for Dentistry and Nursing-Jeddah, Kingdom of Saudi Arabia.

The inclusion criteria were dentulous periodontally free patients in need of dental supragingival scaling. Patients with no history of antibiotic therapy or periodontal treatment for at least six months preceding the study, no history of medication known to affect bone turnover, no systemic illness known to affect bone turnover, no pregnancy, lactation, or menopause for female patients, no history of smoking, and those who were willing and able to return for multiple follow-up visits were included. In addition, the covering mucosa was free from any signs of inflammation or ulceration. The patients provided written informed consent. This study was conducted in accordance with the Helsinki Declaration of 1975 for medical studies, as revised in 2000.

With respect of the standardization of all factors except for the radiographic stents, every patient received two stents. Thus, all of the patients had to participate in two groups. First, they used the stent of Group I then the stent of Group II. The patients were divided into two groups according to the stent used during the radiographic measurements. Group I included the 20 patients while using the customized X-ray positioning stent. Group II included the 20 patients while using the conventional acrylic stent.

The customized stent of Group I was fabricated for each patient for the right and left maxillary and mandibular arches to ensure that it was possible to be fabricated for any site. The acrylic stent of Group II was fabricated for each patient for the right and left maxillary and mandibular arches to ensure that it was possible to be fabricated for any site. After receiving the stents, two radiographic digital radiographs were taken, one upon receiving the stent and the other 3 months later. The mandibular right second premolar was selected to perform the linear measurements on the second premolar.

### 2.1. Fabrication of customized X-ray positioning stent for group I

A special radiographic template was fabricated to allow easy and accurate radiographing of the dentulous patient. According to the required arch, an alginate impression was taken for the maxillary or mandibular arch with fully extended borders. A stone cast was fabricated on the impression (Fig. 1a).

A hard, clear 2 mm thick resin sheet was adapted to the cast through a vacuum forming machine used for the fabrication of the nightguard (Fig. 1b). L-shaped self-curing acrylic resin bite blocks (right and left) were fabricated on the occlusal surface of the adapted resin sheet at the premolar-molar region without adding excess thickness to the nightguard to allow the sensor to reach the periapical region. The L-shaped bite block aids in retaining the plastic film holder in the paralleling radiographic technique (Fig. 1c).

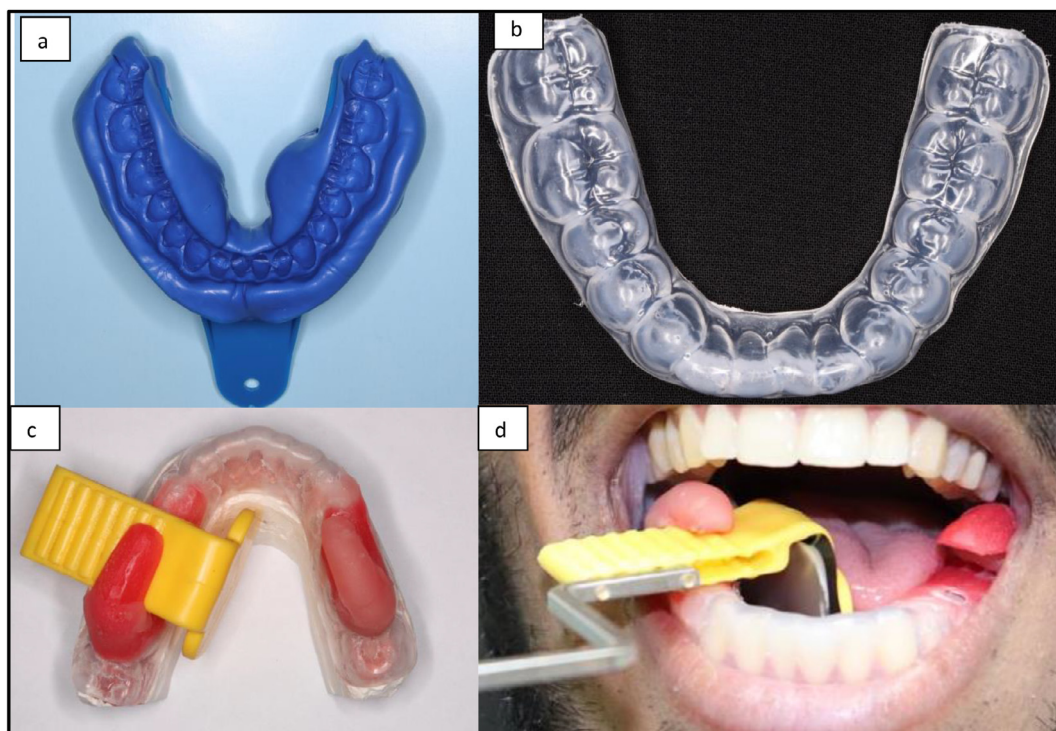
The radiographic stent was then checked in the patient's mouth. It should fit the teeth well, providing adequate retention and stability and permitting free lip and tongue movements (Fig. 1d).

### 2.2. Fabrication of acrylic resin stent for group II

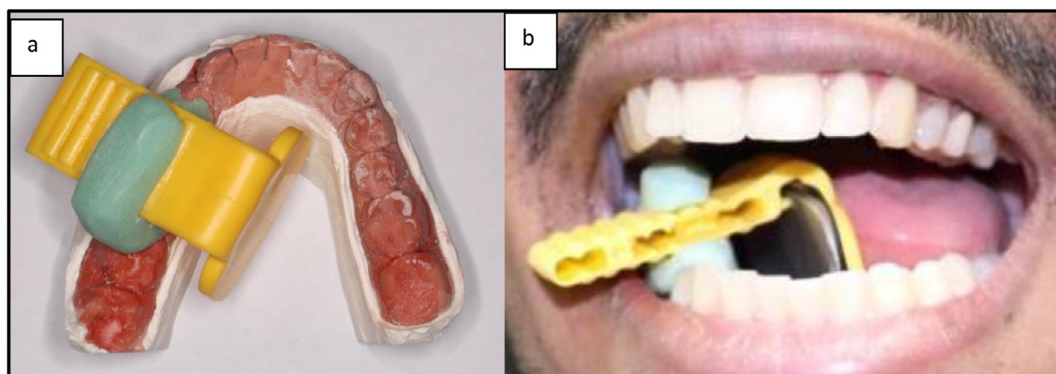
According to the required arch, an alginate impression was taken for the maxillary or mandibular arch with fully extended borders. A stone cast was fabricated on the impression L-shaped self-curing acrylic resin bite blocks (right, left, and maxillary, mandibular) fabricated on the occlusal surface at the premolar-molar region. The L-shaped bite block aids in retaining the plastic film holder in the paralleling radiographic technique (Fig. 2a). The radiographic stent was then checked in the patient's mouth. It should fit the teeth well, providing adequate retention and stability (Fig. 2b).

### 2.3. Radiographic projection

The paralleling technique was used to take digital intra-oral periapical radiographic images initially upon receiving the stents and after a 3-month follow-up period. It was performed using an extension cone paralleling (XCP) film holder for the posterior teeth. A semi-direct digital intra-oral radiographic



**Fig. 1** (a) Lower impression. (b) Nightguard. (c) L-shaped self-curing acrylic resin bite blocks (right and left) fabricated on the occlusal surface of the adapted resin sheet at the premolar-molar region. (d) The radiographic stent was then checked in the patient's mouth.



**Fig. 2** (a) L-shaped self-curing acrylic resin bite blocks. (b) The radiographic stent was then checked in the patient's mouth.

system (Digora, Optime, Soredex, Tuusula, Finland) was used with a size 2 photostimulable phosphor (PSP) imaging plate as an image receptor.

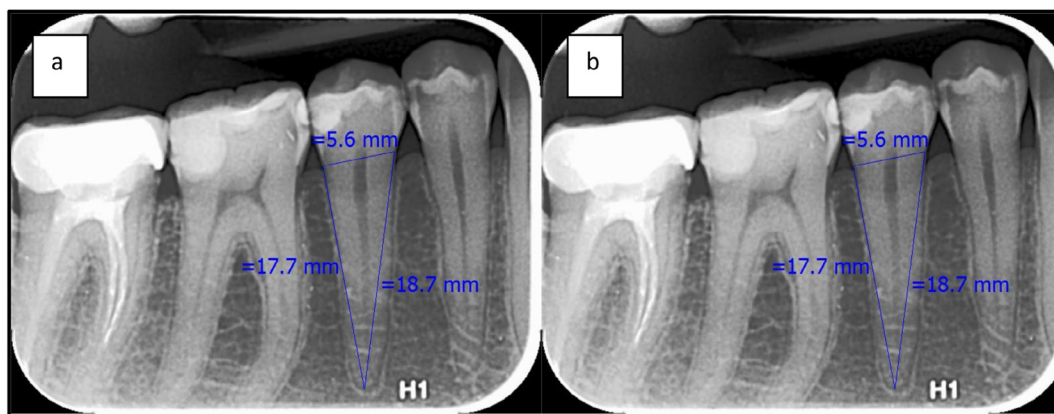
A 70 kVp, 7 mA, and 0.08 sec. exposure time with an approximately 30 cm focal film distance were the exposure parameters used for taking the digital radiographs. After removing any metallic objects, the radiographic stent with the film holder attached to the radiographic sensor was inserted in the patient's mouth and the patient was instructed to close lightly on the bite block. After fixing the position indicating device (PID) and radiation exposure, the sensor was inserted into the laser scanner for digital processing.

#### 2.4. Radiographic evaluation of tooth height

- Quantitative information regarding the linear measurements of the tooth height and width were obtained through the digital imaging system software.

##### 2.4.1. Linear measurements of tooth height

Two lines were drawn from the cementoenamel junction (CEJ) at each side of the tooth to the root apex. The measurements were performed twice by the same observer and the mean of the trials was calculated.



**Fig. 3** Group I linear measurements. (a) Initial measurements. (b) Three-month follow-up measurements.

#### 2.4.2. Linear measurements of tooth width

A line was drawn from along the cemento-enamel junction (CEJ) mesiodistally to calculate the width of the tooth. The measurements were performed twice by the same observer and the mean of the trials was calculated.

For Group I, linear measurements were taken for the width of the mandibular premolar at the CEJ and the height from the CEJ to the apex initially upon receiving the stent and after a 3-month follow-up period (Fig. 3a, b). For Group II, linear measurements were taken for the width of the mandibular premolar at the CEJ and the height from the CEJ to the apex initially upon receiving the stent and after a 3-month follow-up period (Fig. 4a, b).

### 3. Statistical analysis

The mean and standard deviation values were calculated for each group in each test. The data were explored for normality using the Kolmogorov-Smirnov and Shapiro-Wilk tests. The data showed parametric (normal) distribution. The independent sample *t*-test was used to compare the non-related samples between the two groups. The significance level was set at  $p \leq 0.05$ . The statistical analysis was performed with IBM SPSS Statistics Version 20 for Windows.

## 4. Results

### 4.1. Width results

#### Effect of groups

##### A) At 0 m

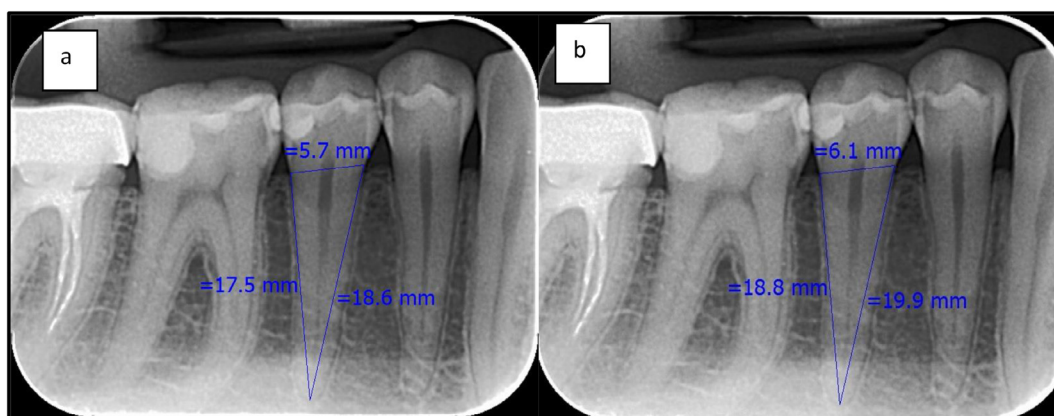
There was no statistically significant difference between Group I and Group II when  $p = 0.327$ . The highest mean value was found in Group I, while the least mean value was found in Group II.

##### B) At 3 m

There was a statistically significant difference between Group I and Group II when  $p < 0.001$ . The highest mean value was found in Group II, while the least mean value was found in Group I (Table 1, Fig. 5).

#### • Overall width change

There was a statistically significant difference between Group I and Group I when  $p < 0.001$ . The highest mean value



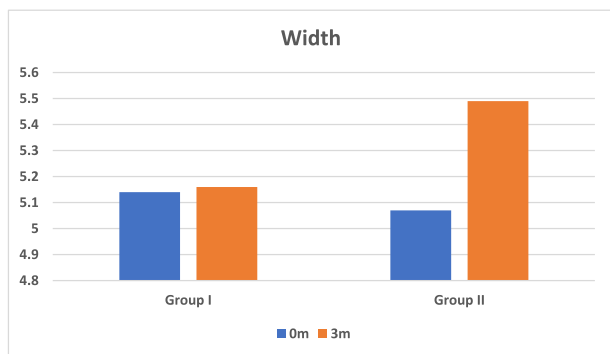
**Fig. 4** Group II linear measurements. (a) Initial measurements. (b) Three-month follow-up measurements.

**Table 1** The mean and standard deviation (SD) values of the width of the different groups.

Variables	Width				p-value
	Group I		Group II		
	Mean	SD	Mean	SD	
<b>0 m</b>	5.14	0.19	5.07	0.23	0.327 ns
<b>3 m</b>	5.16	0.25	5.49	0.23	< 0.001
<b>p-value</b>	<b>0.700 ns</b>		<b>&lt; 0.001*</b>		

ns, non-significant (p > 0.05).

\* Significant (p < 0.05).



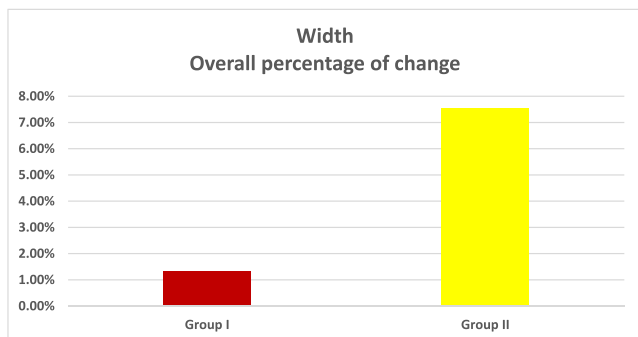
**Fig. 5** Bar chart representing the width of the different groups.

**Table 2** The mean and standard deviation (SD) values of the percentage of the width change of the different groups.

Variables	Width	
	Overall percentage of change	
	Mean	SD
<b>Group I</b>	1.31%	1.44
<b>Group II</b>	7.55%	1.90
<b>p-value</b>	<b>&lt; 0.001*</b>	

ns, non-significant (p > 0.05).

\* Significant (p < 0.05).



**Fig. 6** Bar chart representing the percentage of the width change of the different groups.

was found in Group II, while the least mean value was found in Group I (Table 2, Fig. 6).

4.2. Height results

Effect of groups

A) At 0 m

There was no statistically significant difference between Group I and Group II when p = 0.816. The highest mean value was found in Group II, while the least mean value was found in Group I.

B) At 3 m

There was a statistically significant difference between Group I and Group II when p = 0.012. The highest mean value was found in Group II, while the least mean value was found in Group I (Table 3, Fig. 7).

• Overall height change

There was a statistically significant difference between Group I and Group II when p < 0.001.

The highest mean value was found in Group II, while the least mean value was found in Group I (Table 4, Fig. 8).

5. Discussion

To reduce any periodontal changes, the subjects in this study were limited to individuals in their twenties who did not have periodontal diseases. As reference points during the DSR procedure, the CEJ width for evaluating the horizontal projection angulation and the CEJ and apices for evaluating the vertical projection were chosen. The cusps and the inciso-proximal angles were not chosen due to a higher probability of changing overtime because of fractures or attrition especially if there was an interval of several months between the serial images evaluating a clinical situation (Huh et al., 2005).

Controlling the effect of the irreversible projection errors is the greatest challenge in the clinical application of DSR. When the horizontal or vertical angulations of the X-ray beam related to the object are changed between baseline and follow-up, irreversible projection errors are introduced (Mol et al., 2003). A series of standardized radiographs are used to achieve a precise evaluation of the bony changes around

**Table 3** The mean and standard deviation (SD) values of the height of the different groups.

Variables	Height				p-value
	Group I		Group II		
	Mean	SD	Mean	SD	
<b>0 m</b>	15.79	0.71	15.84	0.63	<b>0.816 ns</b>
<b>3 m</b>	15.81	0.66	16.52	0.99	<b>0.012*</b>
<b>p-value</b>	<b>0.470 ns</b>		<b>0.012*</b>		

ns, non-significant (p > 0.05).

\* Significant (p < 0.05).

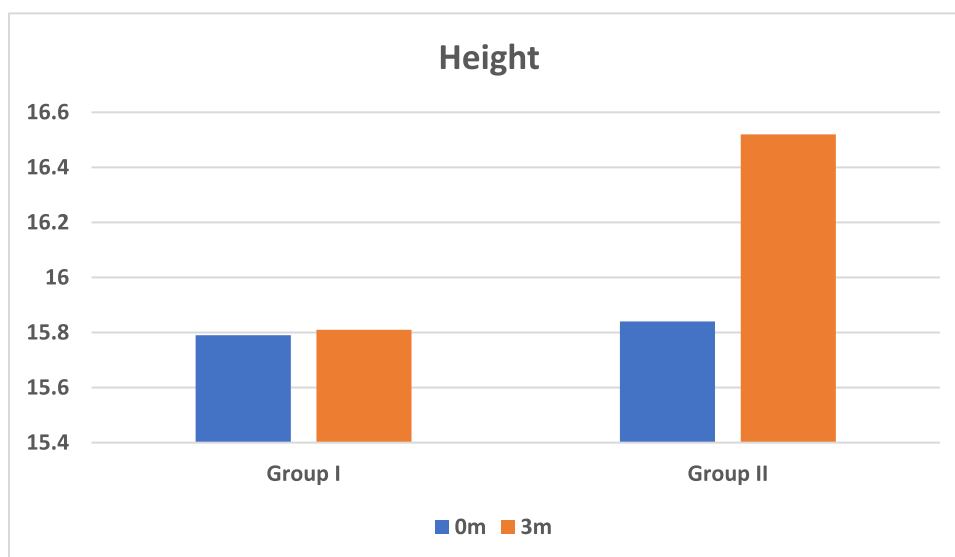


Fig. 7 Bar chart representing the height of the different groups.

**Table 4** The mean and standard deviation (SD) values of the percentage of the height change of the different groups.

Variables	Height	
	Overall percentage of change	
	Mean	SD
<b>Group I</b>	0.70	0.07
<b>Group II</b>	6.91	2.94
<b>p-value</b>	<b>&lt; 0.001*</b>	

ns, non-significant ( $p > 0.05$ ).

\* Significant ( $p < 0.05$ ).

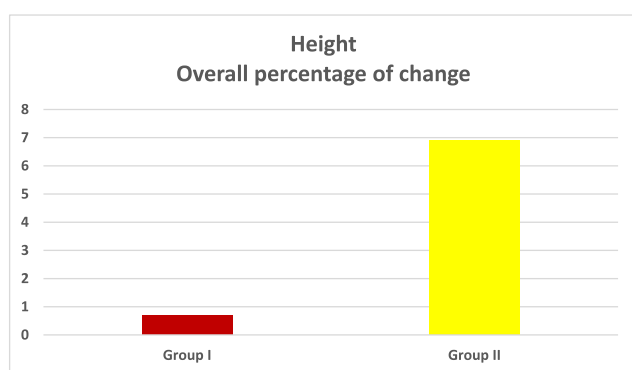


Fig. 8 Bar chart representing percentage of change in height for different groups.

dental implants. Payne et al. (1999); outlined that the major difficulties to achieving a standardized radiograph are the radiographic beam angulation, anatomical variations, the measurement errors on the image, and the quality of the film development. Sewerin (1990); postulated that to achieve accurate results of marginal bone loss, strict parallelism should be achieved, although they stated that parallelism between the

film plane and fixture axis is accompanied by difficulties in the clinical applications (Schulze and d'Hoedt, 2001).

In a study focused on a comparison between different radiographic techniques, the paralleling radiographic technique with a customized bite block was considered a standard of reference. For the DSR technique, the paralleling radiographic technique with a customized bite block was favored. However, the paralleling technique using only XCP could be a match for the DSR procedure in the mandibular anterior region (Huh et al., 2005). An impression material such as a stent retained by the teeth positioned in the axis of the X-ray beam is used to fix most film holders to prevent superimposable radiographs. Geometrically speaking, such a structure is quite optimal because the beam's center of rotation is conventionally close to the area of concern, which minimizes the successive projected image distortion. Nonetheless, a restriction has to be made on the impression material, which is often similar to a stent to the occlusal surface of the teeth. This will prevent interactions with the radiographic image; moreover, for improved support, the stent can be made longer, crossing the arch to the opposite side (Zappa et al, 1991, Janssen and van Aken, 1989). Attaining a consistent film or sensor in the area of interest alignment is achieved by crossing the arch for stabilization of the defined stent that integrates with the XCP bite block and creating the precise position of the sensor or film for each successive radiographic image, which omits the source of the misalignment. Over time, deterioration and distortion occur when small vertical and horizontal planar rotations of the detector related to the object are allowed through unilateral bite blocks with flexible material. Some authors demonstrated that the usage of bite blocks made of silicon materials showed no improvement in the measurements of the bone level (Fernández-Formoso et al., 2011).

Grondahl et al. (1984); found that mis-angulations of 3 degrees or more significantly reduced the diagnostic accuracy of subtracted images. Janssen et al. used an in vitro test to assess the influence of projection error steps of 0.7 degrees on the subtraction analysis. Consequently, it was concluded that 0.7-degree errors had minimal effects on the diagnostic

accuracy, whereas 1.4-degree errors had a significant influence on the diagnostic change accuracy, especially in small surface areas.

Alveolar bone loss is evaluated through measuring the bony changes from sequential radiographs or by density techniques such as DSR as is currently achieved in clinical practice. Methods such as these are quickly altered by modifications of the geometrical projection of successive peri-apical radiographs as this alters the image of the anatomical structure superimposition and inhibits the different trabecular patterns of the cancellous bone. Furthermore, a limit to the diagnostic value of conventional radiographs with controlled angular variations is observed from the outcome produced by the high radiopacity of the dental implants, together with the intra- and inter-examiner variability (Kavadella et al, 2006). Accordingly, the critical factors for the correct evaluation of density changes and bone levels between consecutive images are X-ray standardization and the degree to which all of the details can be superimposed, especially at the alveolar crest. Although the XCP system is superior for achieving a standardized X-ray, it does not allow replication of the film placement or image density normalization (Couture et al, 2005). Hence, the orientation of the X-ray beam is the greatest origin of distortion and irreversible misalignment when considering the use of a rigid splint to position the sensor. It was claimed that the angulation difference between the detector holder and the central beam is more beneficial for interpreting radiographic changes than the angulations between the detector and the field of interest (Roeder et al, 2010). Standardizing the geometry for DSR assembling the impression bite block connected to an XCP is beneficial, but is often difficult, inconvenient, and time-consuming (Huh et al., 2005). In a study comparing the different radiographic sites and the X-ray projection, each projection angle difference had errors at the alveolar bone level on the DSR images. Using the radiographic technique, the number of errors increased from the anterior, premolar, and molar regions except in the mandibular arch, where the molar region had fewer errors compared to the premolar region. Comparing both arches at the premolar-molar region, there were fewer errors in the mandible than in the maxilla. The maxillary molar region had the most errors. The anterior region in both arches had the fewest errors (Huh et al., 2005).

The difference in the projection geometry was the main flaw in this study and caused imprecise DSR images. This was due to the difficulty in the selection of a fixed reference point between the first and succeeding images. Subsequently, it caused errors in the obtained images that led to more errors in the anterior, premolar, and molar regions, and there were fewer errors in the mandibular premolar-molar region than in the maxilla. The selection of a fixed reference point had the main influence on these errors in the serial images. The buccolingual width in the molar teeth, which was larger than the anterior teeth, and the vertical angulation of the projection, which was larger in the maxilla compared to the mandible due to the difficulty of placing the X-ray sensor, were the two factors causing the main difference in achieving a fixed reference point that could easily change the location of the CEJs on the serial images (Björn et al, 1975). Considering the preceding research and information, this study was conducted to verify a bilateral nightguard stent used with an acrylic film holder as a whole X-ray positioning stent used in the mandibular premolar-molar region to be a precise and reliable method

facilitating the follow-up of radiographically dependent research.

Although there was a slight increase in the measurements' mean difference of the height analysis of the successive images in Group I, the differences were non-significant. This, in conjunction with the CEJ width analysis, reinforced the validity of the method in Group I to carry out linear measurements for follow-up assessment radiographs. On the contrary, there was a significant difference in both analyses, indicating that it is an unreliable method. These findings agreed with the results of Messias et al. 2013; who recommended the usage of the acrylic X-ray positioning stent as this X-ray alignment device minimizes the alignment errors between two successive radiographs.

## 6. Conclusion

For long-term follow-up, a precise standardized radiograph is of great importance for accurate linear evaluation as the geometrical projection is controlled and reproducible for the diagnostic value of densitometry and subtraction techniques. In the present study, a customized X-ray positioning stent was fabricated using a nightguard attached to an acrylic bite block bilaterally to prevent angular distortion and alignment errors and to facilitate bilateral follow-up in a comfortable way for both the clinician and the patient.

## Funding

This research did not receive any financial support.

## Ethical Statement

The patients agreed with a written informed consent. The study was conducted in accordance with the Helsinki Declaration of 1975 for medical studies, as revised in 2000.

## Declaration of Competing Interest

The authors declared that there is no conflict of interest.

## References

- Björn, A.L., Björn, H., Halling, A., 1975. An abbreviated index for periodontal bone height. *Odontologisk Revy.* 26, 225–230.
- Cameron, Stephen M., Anthony Joyce, J., Stephen Brousseau, M., Parker, Harry, 1998. Radiographic verification of implant abutment seating. *J. Prosthet. Dent.* 79, 298–303.
- Couture, R., Dixon, D., Hildebolt, C., 2005. A precise receptor-positioning device for subtraction radiography, based on cross-arch stabilization. *Dentomaxillofac. Radiol.* 34 (4), 231–236.
- Dove, S.B., McDavid, W.D., Hamilton, K.E., 2000. Analysis of sensitivity and specificity of a new digital subtraction system: an in vitro study. *Oral. Surg. Oral. Med. Oral. Pathol. Oral. Radiol. Endod.* 89, 771–776.
- Dubrez, Bertrand, Jacot-Descombes, Sabrina, Cimasoni, Giorgio, 1995. Reliability of a paralleling instrument for dental radiographs. *Oral. Surg. Oral. Med. Oral. Pathol. Oral. Radiol. Endod.* 80, 358–364.
- Eickholz, Peter, Benn, Douglas K., Staehle, Hans J., 1996. Radiographic evaluation of bone regeneration following periodontal surgery with or without expanded polytetrafluoroethylene barriers. *J Periodontol.* 67, 379–385.



- Eickholz, Peter, Kim, Ti-Sun, Benn, Douglas K., Phil, M., Staehle, Hans J., Gainesville, Fla, 1998. Validity of radiographic measurement of interproximal bone loss. *Oral. Surg. Oral. Med. Oral. Pathol. Oral. Radiol. Endod.* 85, 99–106.
- Fernández-Formoso, N., Rilo, B., Mora, M.J., Martínez-Silva, I., Santana, U., 2011. A paralleling technique modification to determine the bone crest level around dental implants. *Dentomaxillofac. Radiol.* 40 (6), 385–389.
- Grondahl, Kerstin, Grondahl, Hans-Goran, Webber, Richard I., 1984. Influence of variations in projection geometry on the detectability of periodontal bone lesions: a comparison between subtraction radiography and conventional radiographic technique. *J. Clin. Periodontol.* 11, 411–420.
- Huh, Kyung-Hoe, Lee, Sam-Sun, Jeon, In-Seong, Yi, Won-Jin, Heo, Min-Suk, Choi, Soon-Chul, 2005. Quantitative analysis of errors in alveolar crest level caused by discrepant projection geometry in digital subtraction radiography: an in Vivo Study. *Oral. Surg. Oral. Med. Oral. Pathol. Oral. Radiol. Endod.* 100 (6), 750–755.
- Janssen, P.T., van Aken, J., 1989. Problems around the in vitro and in vivo application of quantitative digital subtraction radiography. *J. Clin. Periodontol.* 16, 323–330.
- Kavadella, A., Karayiannis, A., Nicopoulou-Karayianni, K., 2006. Detectability of experimental peri-implant cancellous bone lesions using conventional and direct digital radiography. *Aust. Dent. J.* 51 (2), 180–186.
- Kuhl, E.D., Nummikoski, P.V., 2000. Radiographic absorptiometry method in measurement of localized alveolar bone density changes. *Oral. Surg. Oral. Med. Oral. Pathol.* 89 (3), 375–381.
- Laurell, L., Lundgren, D., 2011. Marginal bone level changes at dental implants after 5 years in function: a meta-analysis. *Clin. Implant. Dent. Relat. Res.* 13 (1), 19–28.
- Messias, Ana, Tondela, João Paulo, Rocha, Salomão, Reis, Rita, Nicolau, Pedro, Guerra, Fernando, 2013. Acrylic customized X-ray positioning stent for prospective bone level analysis in long-term clinical implant studies. *Open J. Radiol.* 3, 136–142.
- Mol, A., Dunn, Stanley M., Chapel Hill, NC, and Piscataway, NJ, 2003. The performance of projective standardization for digital subtraction radiography. *Oral. Surg. Oral. Med. Oral. Pathol. Oral. Radiol. Endod.* 96, 373–382.
- Payne, A.G.T., Solomon, Y.F., Lownie, J.F., 1999. Standardization of radiographs for mandibular implant-supported overdentures: review and innovation. *Clin. Oral. Impl. Res.* 10, 307–319.
- Roeder, F., Brüllmann, D., d’Hoedt, B., Schulze, R., 2010. Ex vivo radiographic tooth length measurements with the reference sphere method (RSM). *Clin. Oral. Invest.* 14 (6), 645–651.
- Schulze and d’Hoedt, 2001. Mathematical analysis of projection errors in “paralleling technique” with respect to implant geometry. *Clin. Oral. Impl. Res.* 12, 364–371.
- Schulze, Ralf, Bruellmann, Dan Dominik, Roeder, Felix, d’Hoedt, Bernd, 2004. Determination of projection geometry from quantitative assessment of the distortion of spherical references in single-view projection radiography. *Med. Phys.* 31, 2849–2854.
- Sewerin, I.P., 1990. Errors in radiographic assessment of marginal bone height around osseointegrated implants. *Scand. J. Dent. Res.* 98 (5), 428–433.
- Updegrave, W.J., 1951. The paralleling extension-cone technique in intraoral dental radiography. *Oral. Surg. Oral. Med. Oral. Pathol.* 4 (10), 1250–1261.
- Wakoh, M., Harada, T., Otonari, T., Otonari-Yamamoto, M., Ohkubo, M., Kousuge, Y., Kobayashi, N., Mizuta, S., Kitagawa, H., Sano, T., 2006. Reliability of linear distance measurement for dental implant length with standardized periapical radiographs. *Bull. Tokyo Dent. Coll.* 47 (3), 105–115.
- Zappa, U., Simona, C., Graf, H., Van Aken, J., 1991. In vivo determination of radiographic projection errors produced by a novel film holder and an X-ray beam manipulator. *J. Periodontol.* 62, 674–683.