Master Thesis

Standardized and individualized vertical bitewing radiographs for a digital x-ray system

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Content

1 Abstract

Intraoral radiographs are important tools for diagnosing, monitoring and evaluating the treatment of infrabony lesions. However, different beam angulations between exposures may give a wrong interpretation when evaluating them. A technique that is useful for monitoring bone loss and regeneration is the use of subtraction radiography. This technique is also very sensitive for changes in projection geometry, thus highly standardized radiographs are required. Previous attempts have been made to standardize and individualize vertical bitewing holders in conventional radiographs by Duckworth et al. (1983). The aim of the present study was to develop a similar system for digital radiographs that can be used on a routine basis with minimal effort in the clinic in the case of infrabony and furcational lesions. The radiographs were also tested for the subtraction technique. For this study, vertical bitewings with an aiming device were employed. Wire markers were incorporated into the holders to enable measurements of angular variations and an occlusal index was used for individualization. The radiographs were taken on phantom heads. In total, 2 sets of measurements on 36 exposures were compared. Radiographs with a difference in projection geometry within 2 degrees were found to be acceptable for using the subtraction technique. 58% of the comparisons lie within this limit, both horizontally and vertically. It was concluded that by knowing which distances correspond to which degrees, the technique can easily be used in a clinical setting.

2 Introduction

Periodontal disease is a common condition characterized by loss of the supportive apparatus of teeth including the alveolar bone (Armitage 2000). In more advanced forms a common feature is the presence of infrabony lesions (Papapanou and Tonetti 2000). These lesions have been described as angular or vertical bone loss. They seem to increase the risk of progression of the disease if appropriate treatment is not given (Papapanou and Wennström 1991). Intraoral radiographs are very important tools in diagnosing, monitoring and evaluating the treatment of infrabony lesions (Jeffcoat et al. 2000). Highly standardized intraoral radiographs are required for documentation of treatment results of advanced periodontitis, including bone gain in infrabony lesions. Sources of error when comparing consecutive radiographs include projection geometry, distortion of films and contrast/brightness due to varying exposures to the x-ray source (Hausmann et al. 1991). One challenge in utilizing intraoral radiographs is that the central ray angulation differs slightly from each projection, and may give a wrong interpretation when evaluating them (Hausmann et al. 1989). When taking intraoral images, there will always be some discrepancy in the angle and distance between the primary image and the follow-up. This is inevitable unless one has something to aid in the taking of the radiograph, ensuring similar projection angles on the primary and the follow up pictures. Furthermore, understanding the difficulty of attaining this similarity, it is wise to have a tool for calculating any discrepancy and taking this into account when evaluating the difference between two exposures taken at different times. Achieving such a system will make it possible to monitor bone regeneration after periodontal treatment, and also follow the progression of an ongoing disease, comparing intraoral radiographs taken before and after treatment. A technique for monitoring bone loss and regeneration is subtraction radiography (Gröndahl et al. 1983, Kulczyk et al. 2006). The technique was introduced by Gröndahl in 1983 and has been shown to be more sensitive to detect smaller radiographic changes on serial radiographs than conventional analysis, but it is very sensitive to changes in projection geometry (Hausmann et al. 1991). Studies have shown that the level of standardization of the projection geometry greatly influences the performance of the subtraction radiography (Schulz et al. 1991, Hausmann et al. 1985). In bitewing images, the beam is oriented at right angles to the long axis of the teeth, compared to periapicals in the same area, thus providing less distortion. With periapicals it is often difficult to attain the same 90-degree angulation because of the palate and the floor of the mouth hindering parallel placement of the film with the teeth (Hausmann et al. 1989, Polson and Reed 1984). One can cover a greater area in the apical direction with a vertical bitewing compared to a horizontal, thus capturing the full depth of a potential infrabony lesion. Based on this knowledge vertical bitewings were used in this study. Previously, attempts have been made, in conventional radiography, to reduce the problem to vertical and horizontal angles between subsequent exposures by using vertical bitewing films which avoid film distortion, aluminium or copper step wedges for brightness/contrast correction, and individualization of the film holder with resin or silicon tooth impressions while taking the image (Duckworth et al. 1983). Attempts have also been made for the direct technique in the digital system (Muratore et al. 2001). The aim of the present study was to develop a similar system for digital intraoral radiographs that can be used on a routine basis with minimal effort in the clinic in cases of infrabony and furcational lesions, and also to decide a threshold for angular variation in projection geometry in order to use the subtraction technique. This was done by adapting and modifying the technique developed by Duckworth et al. (1983) for an indirect digital radiographic system, using vertical bitewing film holders with alignment rings. The film holders were individualized in addition to making markers on the holders so as to be able to calculate any discrepancy. By taking several images with the same holders one could then check the reproducibility of the holders, as well as calculate the difference in beam angulation between the primary image and the follow-ups.

3 Background

3.1 Periodontal disease and infrabony lesions

Periodontal diseases include a range of pathological conditions from mild periodontitis to severe periodontitis. Gingivitis is always the precursor, but does not necessarily lead to periodontitis. Today we cannot distinguish a potentially progressing form of gingivitis from a stable form (Kesic et al. 2010). It is therefore of utmost importance to discover signs of destructive periodontal disease at an early stage, or to predict the risk for further destruction after treatment. Both gingivitis and periodontitis are graded from mild to severe according to the severity of the condition (Amercian Academy of Periodontology 1999). The etiological factors of periodontal disease are complex, but there is broad agreement of bacteria within the biofilm playing an important role in the development of periodontitis (Kesic et al. 2010). Even though the etiology is complex, the aim of treatment is mechanic removal of biofilm and calculus to both prevent and treat the disease. Periodontal pockets are usually characterized by probing depths of at least 4 mm and loss of clinical periodontal attachment. If the bottom of the pocket is located apically to the alveolar crest it is called an infrabony lesion. In the more advanced cases there might be infrabony lesions present in one or more locations. These are further subdivided into 3, 2 and 1 bony wall defects, and craters, the last being the most severe (Papapanou and Tonetti 2000). The prognosis is dependent on the severity of the disease, the treatment given, and highly of the patient cooperation to improve their dental hygiene as well quit habits that prevent optimal healing, such as smoking (Machtei et al. 1997, Leininger et al. 2010). To diagnose the disease and do follow-ups, one uses a probe to measure the pocket depths clinically. In addition, intraoral radiographs are highly important in aiding the diagnosis. This provides an insight subgingivally without being too invasive (Jeffcoat et al. 1995). It is a helpful tool to measure the relationship between the root and the bone level to consider the overall level of the alveolar crest (Armitage 2004). It also gives an impression of the width of the periodontal ligament and the presence or absence of lamina dura. Furthermore it helps detect furcation involvement and the presence of infrabony lesions (Mol 2004). It does not, however, provide a complete picture. Standard radiographs present severe limitations for the assessment of the periodontal status or of the progress of a particular infrabony lesion. The limitations include structural noise in the radiographs and also the variations between the primary and follow up radiographs (Putnins et al. 1988). One way of improving the diagnostic accuracy is the use of subtraction radiography (Putnins et al. 1988). It is performed by superimposing and subtracting a pair of radiographs, the first one as a positive and the second as a negative. The images are also adjusted regarding their translucency when subtracted. The aim is to emphasize differences in the lesion size in the area of interest that may have occurred in the interval between the exposures. The complex background, being the rest of the image, is called the structural noise. This area will in a subtraction radiograph with minimum geometrical variance between the exposures, be kept to a minimum because the similar structures will eliminate each other in the subtraction. With increasing angular variation between the exposures, the structural noise also will increase proportionally (Ruttiman et al. 1982). Thus the difference between the two radiographs used must be kept to a minimum, as the technique is highly sensitive to variations in the projection geometry (Likar et al. 1996). The use of subtraction radiography has shown to improve accuracy in diagnostics of bony defects in periodontal disease considerably compared to conventional radiography (Ruttiman et al. 1982). To be able to take radiographs which meet the criteria for subtraction radiography, and also to use in monitoring bone level after therapy, highly standardized radiographs are required (Benn 1990). There have been several efforts in developing a standardized radiographic system. One of the first ones has been described by Duckworth et al. (1983). In their experiments the patients bit on a holder with an impression material until it fastened. The result was an individualized holder, making it easy to guide the holder in the exact same position next time. Furthermore they constructed a guiding device that could work as help for positioning the collimator at the same angle and distance as done when taking the previous intraoral radiographs. They also had metal wires on the occlusal surfaces of the holders with a known length and distance so as to be able to calculate any angular discrepancies between two exposures.

3.2 Vertical bitewing versus apical radiographs

There is a higher tendency for vertical deviance of the x-ray beam between primary and follow up images in periapical radiographs than in bitewing images (Hausmann et al. 1989). For monitoring and measuring of the alveolar bone, especially in the molar region, it is advisable to utilize intraoral bitewing radiographs (Hausmann et at. 1989). There are higher anatomical limitations imposed on the technique used in periapical radiographs that can, to a certain degree, be avoided using bitewing radiographs (Reed and Polson 1983). Also one can use these radiographs to diagnose caries and monitor the horizontal bone levels, thus minimizing the dose of radiation (Duckworth et al. 1983). Regarding this information, it is reasonable to believe that it is easier to reproduce bitewing images than periapical ones.

4 Materials and methods

4.1 Modifying the holders

The holders used for this study were vertical bitewing holders of the brand Kerrhawe Paro-Bite (Kerr, USA) with alignment rings. In order to modify the holders to meet the requirements, steel wires in cross-sectional forms were attached to the occlusal biting surface (Duckworth et al. 1983). These specific wires had to be placed perpendicular to the film and at a known distance from it. The aim was to have several structures in known forms and at known distances from the film, so as to be able to calculate the deviation from one image to the other of the same area in the mouth. Furthermore there was attached an adequate occlusal index on the biting surface, to aid the patient in biting in the same way when taking the follow-up radiograph (Duckworth et al. 1983). A device to optimize the aim of the central ray angulation was also developed. This was achieved by adding laminated plastic (Esselte Leitz, Sweden) perpendicular to the prefabricated aiming device with the superglue agent Loctite Super Attak Glue (Henkel Corp., USA) to stabilize the collimator, as shown in Fig.1. The prefabricated aiming device simply consisted of a drawn rectangle onto a piece of cardboard, corresponding to the shape and size of the collimator. The prefabricated aiming device was laminated to make it more stable and hardwearing. This cardboard was then attached to the holder by the original aiming ring (Fig.2).

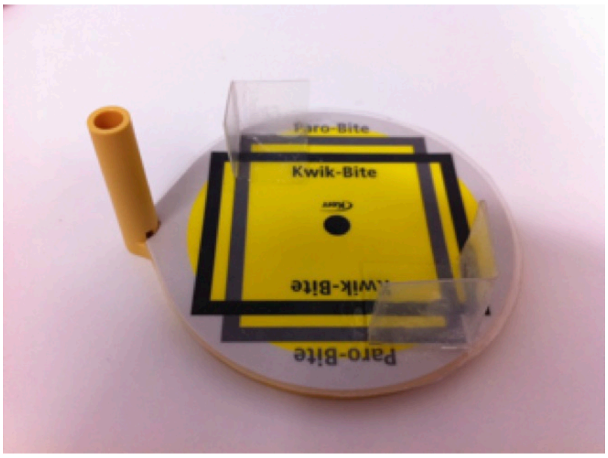

Fig. 1. Aiming device made of laminated plastic.

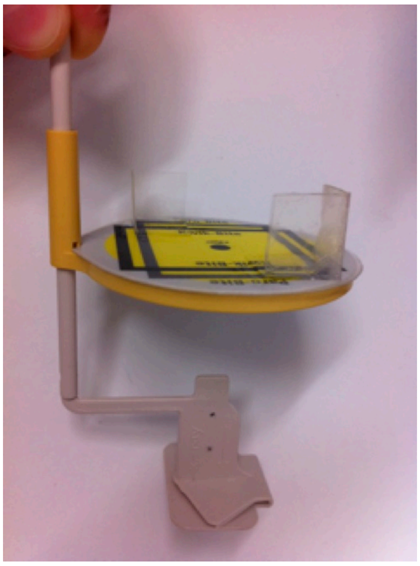

Fig. 2. The holder after modification.

On one side of the bite plane a round orthodontic wire of 10 mm, 0.50 mm in diameter (Fried. Krupp AG Hoesch-Krupp, Germany) was attached 12 mm from the film, parallel to the plate (Fig. 3A). This horizontal wire was used as a calibration standard for image magnification (Duckworth et al. 1983). It has been shown that this was the optimal distance to keep the wire in the focal plane of interest, when radiographs are taken in the posterior region (Duckworth et al. 1983). In clinical use it can also provide a measurement endpoint for alveolar crest measurement. On the other side of the bite plane two orthodontic wires were attached, one round sized 0.50 mm (Fried. Krupp AG Hoesch-Krupp, Germany) and one rectangular sized 0.40 x 0.60 mm (ORMCO Corporation, USA), placed coaxially perpendicular to the plate. The distances to the film were 10 mm for the round and 20 mm for the square wire (Fig. 3B). These wires were used to measure the vertical and horizontal deviations between a primary and two follow-up radiographs.

Fig. 3. Modification of the holders. A) Horizontal wire. B) The square and round wire.

In the first attempt, Loctite Super Attak Glue was used to attach all the wires, but this proved to be inadequate, as the wires fell off. Furthermore a composite bonding agent, Clearfill SE bond (Kuraray Co., Japan) was tested for the purpose, but also showed its inadequacy. A combination of mechanical and chemical attachment was finally accomplished by using a round bur to incorporate the wire pieces into the bite plate (Fig. 4), and then super glue to ensure the chemical attachment. The first attempt to fix the occlusal index failed as the retention on the smooth plastic holder was minimal. To improve the attachment of the index to the holder four holes were drilled in each bite plane in order to incorporate mechanical retention (Fig. 5) as an additional element to the adhesive material that was used. VPT Adhesive (3M ESPE, USA) was used as an adhesive material to improve the attachment of the index material to the holders. This turned out to function well. To minimize the systematic errors, two students performed the task of making the holders.

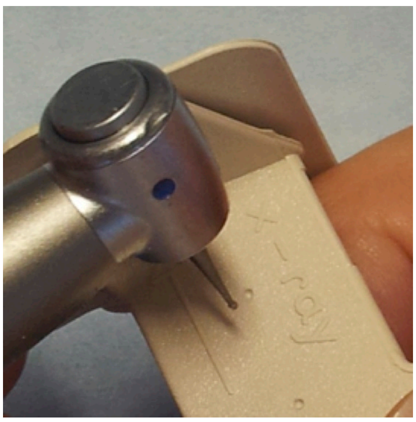

Fig. 4. Mechanical retention made with a round bur.

Fig.5. The holder with drilled holes in order to incorporate mechanical retention.

Several impression materials were used to individualize the film holders (Table 1). A-silicons were expected to be the most suitable material and different products within this category were tested. In addition Protemp™ Crown Temporization Material (3M ESPE, USA) and Kerr Compound Stick Green (Kerr Co., Japan) were tested.

Table 1 Impression materials presented with brand names.

Express STD Putty (3M ESPE, USA)	A-silicon dental impression material
Jet Bite (Coltene, Switzerland).	Dental impression material with A-silicon basis
Protemp (3M ESPE, USA).	Composite
Reline soft (GC Corp., Japan).	Soft material for rebasing with A-silicon basis
Kerr Compound Stick Green (Kerr, Japan).	Thermoplastic impression material-Wax
Flexitime Bite (Heraeus Dental, Germany).	A-silicon
Flexitime® Correct Flow (Heraues Dental, Germany).	A-silicon

Flexitime Correct Flow (Heraeus Dental, Germany) turned out to be the best material (Fig. 6).

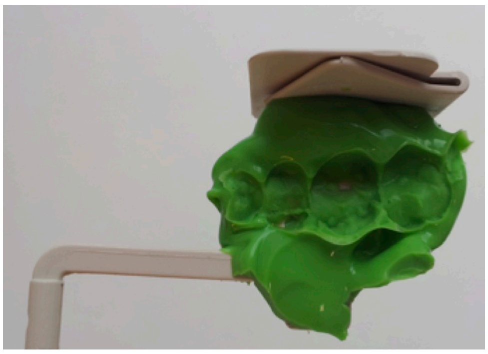

Fig. 6. Flexitime Correct Flow, the material used.

4.2 Taking radiographs with individualized and standardized film holders

The intraoral radiographs taken in this study were performed on three different x-ray trainers (phantom heads) of the type DDTTR-3 (Dentsply Rinn, USA), each with a complete permanent dentition. The x-ray machine (Minray Intraoral X-ray Unit, Soredex, Finland) and developing machine (Classic Digora Optime, Soredex, Finland) were the same in each image. On the x-rays trainers four different intraoral vertical bitewings were taken of each phantom heads: two for premolars and two for the molars. The radiographs were repeated two times resulting in 36 images for measuring. The imaging plates, size 2 (Soredex, Finland), were placed in the holder before the index was made. Then the impression material was applied and the holder placed carefully in the area of interest. The bite was fixed until the impression material had set (Fig. 7A). Then the index was checked and tried in occlusion again. The collimator was aligned, guided by the aiming device on the holder (Fig. 7B).

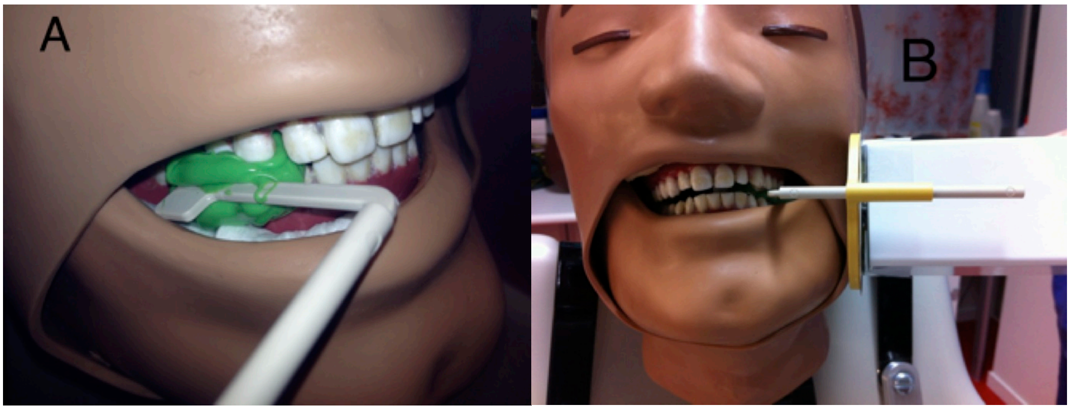

Fig. 7. Adjusting the holder to the phantom head. A) Making the index. B) Guiding the collimator against the aiming device

Each radiograph was then reproduced two more times after a minimum of two days. To minimize systematic errors, two students participated in this task. All the radiographs were taken with 7 mA and 60 kV Volt on the same machine with a tube length of 229 mm. In addition to using the phantom heads, the modified holders were also applied in two patient cases. This was done mainly to show that it could be utilized in the clinic as well. Intraoral radiographs on patients were only taken when indicated, and couldn't be repeated due to ethical concerns. The patients were instructed in biting on the bite block and holding this position while the impression material sat. One of the patients only had teeth in the upper jaw, making it more difficult to take and stabilize the index material, but it was possible. The holders were disinfected and stored for later use.

4.3 Measurements of distances and calculating angular errors

The aberration in distance between similar radiographs was calculated and put in an equation as described by Duckworth et al. (1983), replacing the distances used with the ones used in this study.
From the assumption of a parallel beam, the angular error as illustrated in Fig. 8 is:

$\tan\theta = b/20$ (1)

$b = a + d$ (2)

From distances selected for the coaxial wires

$a/b = 10/20 = 1/2$ or $a = 2/2$ (3)

Thus from equation (2) and (3)

$b = b/2 + d$ or $b = 2d$ (4)

By substitution in equation (1)

$\tan\theta = (2d)/20 = d/10$

Solving for Θ results in the following expression:

$\theta = \arctan d/10$

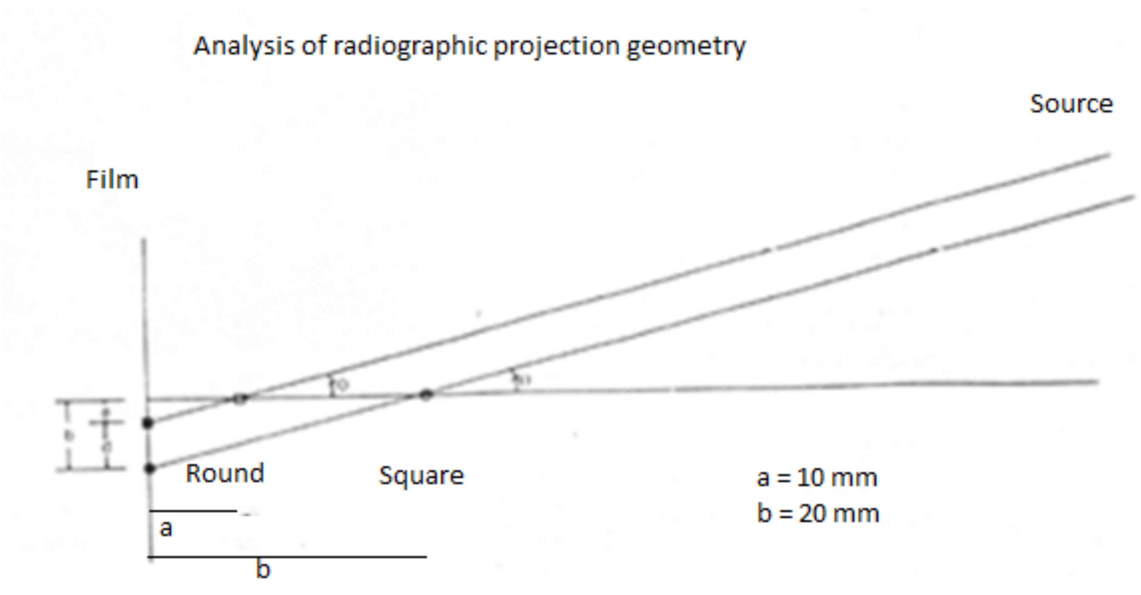

Fig. 8. Illustration of the angular error. *d is the distance between the images of the two wires on the film in horizontal and vertical terms.

The radiographs were enlarged four times to ease the marking of endpoints of the wires and the radiographs were also calibrated according to the actual length of the horizontal wire. The enlargement and calibration was done on the computer using Digora for Windows dental imaging software (Soredex, Finland). A grid system was made in Microsoft Excel (Microsoft Corp., USA) and applied onto the radiographs, each grid representing 2.5 mm both horizontally and vertically (Fig. 9).

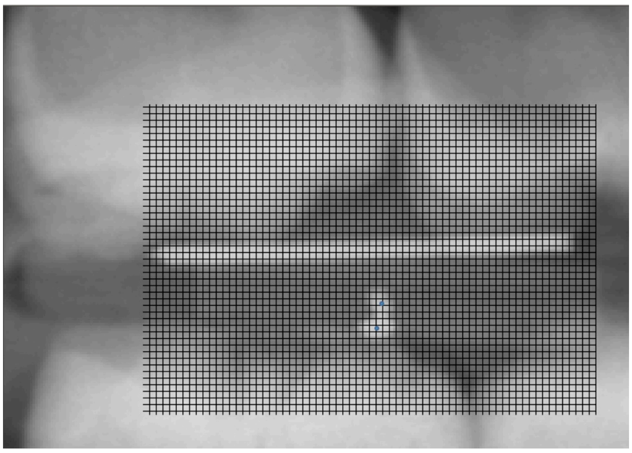

Fig. 9. The grid system used for measuring the distances.

The results were interpreted by two observers independently by hand, and the measurements were plotted into the formula and calculated using a hand calculator in the program STAT (Casio CFX-9850G). All measurements were done in the same room each time with the same light conditions. Deviations between the measurements, average of these deviations, standard deviation and limit of agreement were calculated and presented in a Bland-Altman plot (Bland and Altman 1986) using Microsoft Excel. The average and standard deviation of the results between the two different measurements was then presented by tables and graphs, with the horizontal and vertical deviance separately. The angular variations in projection geometry were categorized in different intervals: 0-1 degree, 1-1.5 degrees, 1.5-2 degrees, 2-2.5 degrees and 2.5-3 degrees. A set of radiographs for each category was used to make a subtraction radiograph, utilizing Adobe Photoshop CS5 (Adobe systems U.S). This was achieved with a set of radiographs taken in the same region. The follow-up radiograph was transformed into a negative and adjusted to a level of 50% translucency. It was then used as an overlay on the primary radiograph, which was kept in its original form. The result was a subtracted radiograph were one could trace differences between the exposures. When using the negative as an overlay, these areas will appear as shades on the image. Evaluating the subtraction radiographs from each category, a threshold of angular variation for this technique was decided.

5 Results

5.1 Impression materials

Testing of different impression materials as an index showed that both Putty and Jetbite were excellent in terms of setting time, but they showed poor adhesion to the x-ray holder. In addition Jetbite was brittle and had a high tendency for fracture. Protemp had an acceptable setting time and bonded to the x-ray holder, but this product couldn't be used because of its radiopacity. GC Reline Soft had a setting time beyond what is clinically acceptable, and was declined for the study. Green Kerr showed itself to be hard to work with being greasy and unmanageable. Flexitime Bite turned brittle after setting and was also declined regarding its fracture tendency. Flexitime Correct Flow was at last the material of choice. It met with all our criteria for this study. It was easy to work with, had an acceptable setting time, and could be stored, according to the manufacturer, for a long period of time, without any distortion of the impression. A summary of all the impression materials is given in Table 2.

Table 2 The impression materials used and their characteristics.

Impression material	
Putty	Poor adhesion to x-ray holder
Jetbite	Poor adhesion to x-ray holder and brittle
Protemp	Radiopaque
GC Reline Soft	Too long setting time
Green Kerr	Hard to work with, greasy and unmanageable
Flexitime Bite	Too brittle
Flexitime Correct Flow	Appropriate

5.2 Inter-examiner reliability of measurements

Two observers measured the horizontal and vertical distances between centres of squared and round wires on images, which have been generated on 3 different phantom heads. The radiographs were taken in 4 regions (premolar and molar area on both sides) in each phantom head, and repeated twice. In total, 2 sets of measurements on 36 exposures could be compared. The average and standard deviation was calculated since there was a high agreement between observer 1 and observer 2.

95 % of the differences between the two calculations should lie within the limit of agreement, which is calculated based on the standard deviation. These results are presented in Table 3. The differences are also illustrated in a Bland-Altman Plot: Vertical deviations in Fig. 10 and horizontal deviations in Fig. 11.

Table 3 The average standard deviation and limit of agreement between the calculations done by observer 1 and observer 2.

	Average of Differences	Standard Deviation	Limit of Agreement
Horizontal	$-2.80E^{-03}$	0.0696	0.1365
Vertical	0.0028	0.0736	0.1443

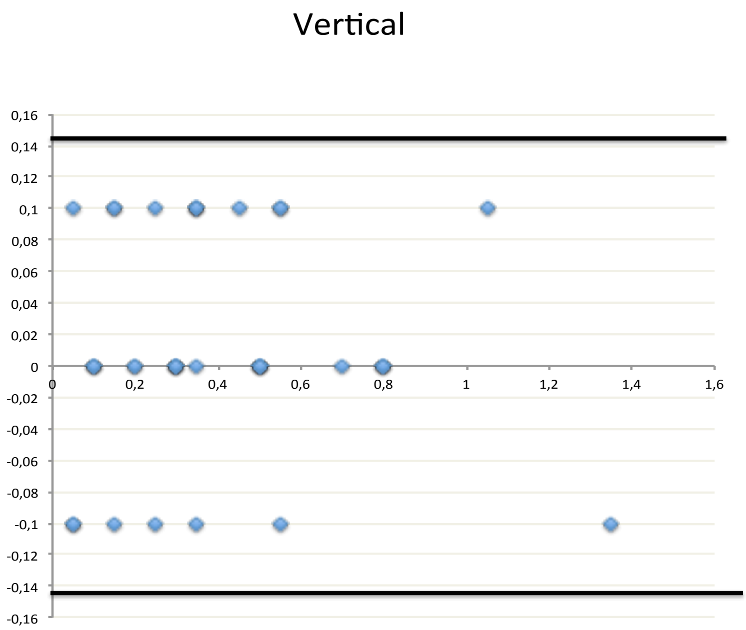

Fig. 10 Deviations between the vertical calculations of observer 1 and observer 2. The limit of agreement is highlighted.

Horizontal

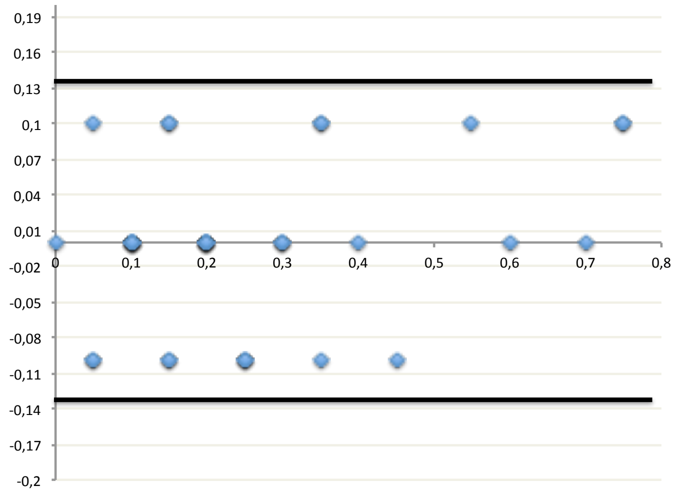

Fig. 11 Deviations between the horizontal calculations of observer 1 and observer 2. The limit of agreement is highlighted.

As these results show, when comparing these calculations to each other, there is a high agreement between the observers and the measurements can be used for further calculations, using an average of the two.

5.3 Calculations of angles

The average of deviations and standard deviation was calculated based on the measurements done by observer 1 and observer 2. The results are presented in Table 4 with the values presented in millimetres, and in Table 5 with the corresponding degrees.

Table 4 Average and standard deviation based on an average of the 2 different measurements. Values are given in millimetres

	Average Deviation	Standard Deviation
Horizontal	0.26	0.20
Vertical	0.40	0.29

Table 5 Average and standard deviation presented in degrees.

	Average	Standard Deviation
Horizontal	1.49	1.12
Vertical	2.27	1.65

The calculations were further categorized based on the degree of deviation. First included are all the deviations not exceeding 3 degrees when comparing, then 2.5 degrees, 2 degrees, 1.5 degrees and 1 degree. These results are presented in Table 6.

Table 6 Distribution of comparisons ranging from an interval of 0 – 3 degrees to an interval of 0-1 degree.

Degrees (interval)	Vertical deviations Number (percent)	Horizontal deviations Number (percent)	Horizontal and vertical deviations Number (percent)
0 – 3	27 (75)	31 (86)	24 (66)
0 - 2.5	22 (61)	30 (83)	21 (58)
0 – 2	22 (61)	29 (80)	21 (58)
0 - 1.5	12 (33)	23 (63)	10 (27)
0 – 1	9 (25)	14 (38)	5 (13)

The calculations presented in Tables 4 and 5 show a high average deviation. However, Table 6 shows that some of the radiographs are presented with high deviations and will affect the average significantly. Even though the average for the vertical deviations is high, 66 % of all the comparisons are below 3 degrees both horizontally and vertically. The results show that of the sets of radiographs taken, 27 of vertical (75%) and 31 of horizontal (86%) deviations were below 3 degrees. The results also show that the tendency for deviation is higher in the vertical than in the horizontal direction. Sets of subtraction radiographs are presented in Fig. 12-16. These subtraction radiographs illustrate deviations both vertically and horizontally below 3 degrees in Fig. 12, below 2.5 degrees in Fig. 13, below 2 degrees in Fig. 14, below 1.5 degrees in Fig. 15 and below 1 degree in Fig. 16.

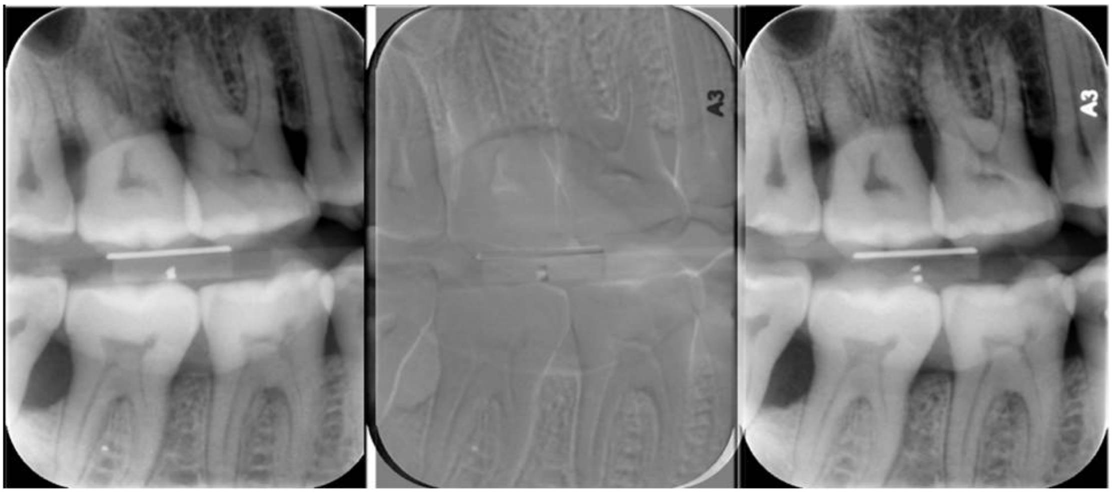

Fig. 12 Subtraction radiograph (middle) with vertical deviation between the two exposures below 3 degrees: vertical deviation 2.86 degrees and horizontal 0.86 degrees.

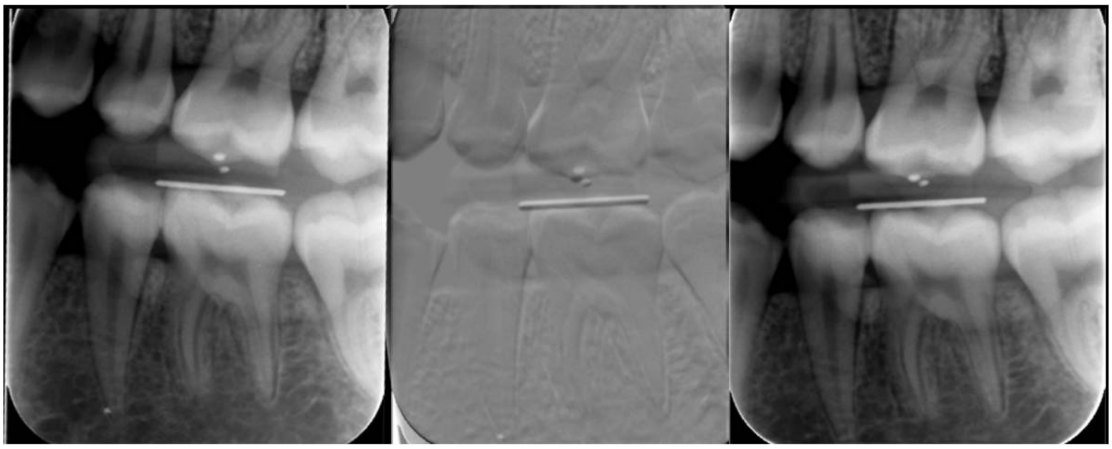

Fig. 13 Subtraction radiograph with both vertical and horizontal deviations below 2.5 degrees: vertical deviation 2.3 degrees and horizontal 2 degrees.

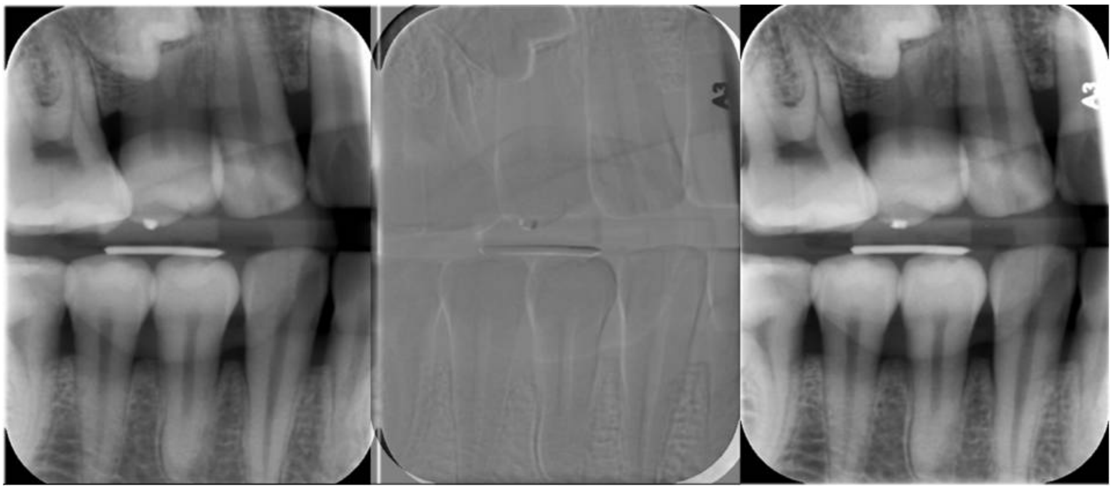

Fig. 14 Subtraction radiograph with both vertical and horizontal deviations below 2 degrees: vertical deviation 1.43 degrees and horizontal 1.71 degrees.

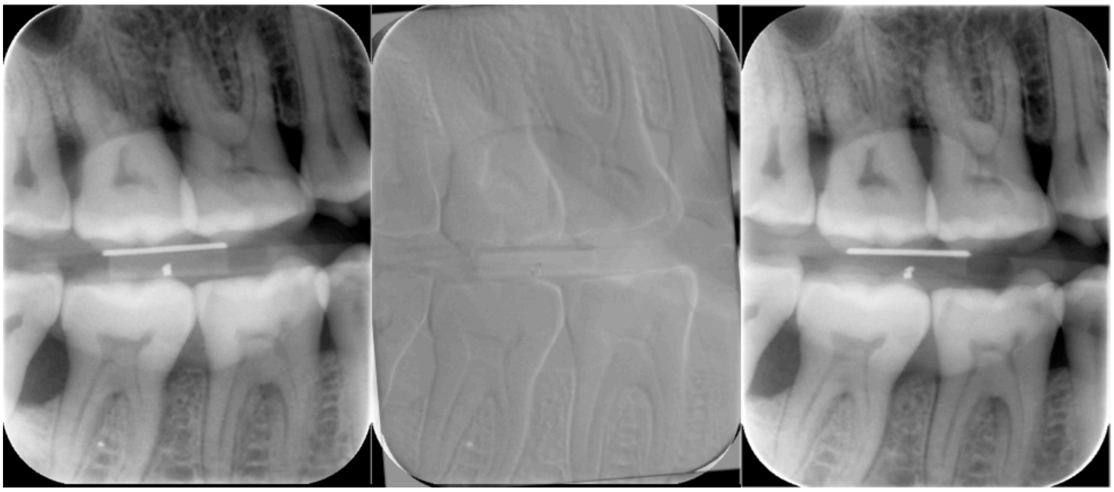

Fig. 15 Subtraction radiograph with both vertical and horizontal deviations below 1.5 degrees: vertical deviation 1.14 degrees and horizontal 1.14 degrees.

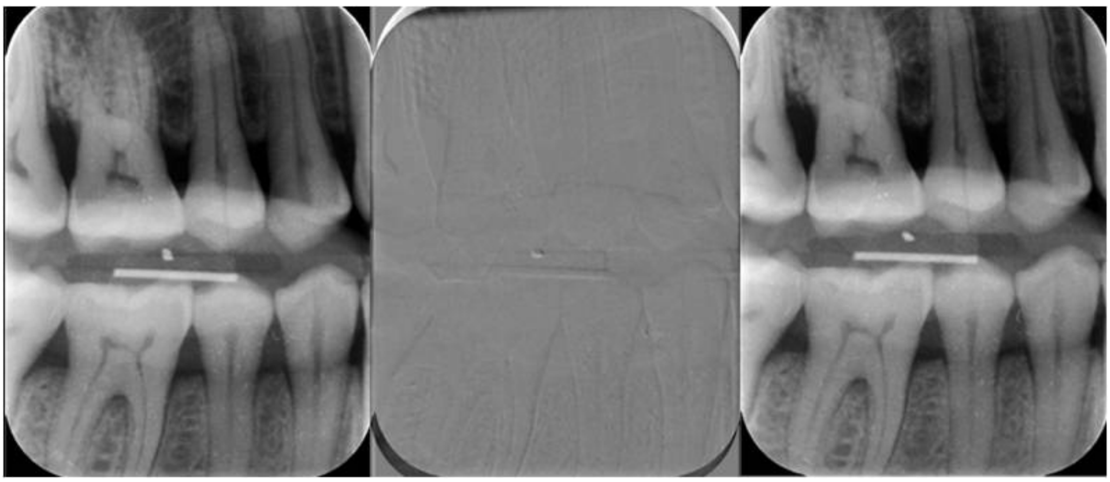

Fig. 16 Subtraction radiograph with both vertical and horizontal deviations below 1 degrees: vertical deviation 0.57 degrees and horizontal 0.85 degrees.

6 Discussion

6.1 Main findings, short presentation of results

The results show that among the sets of radiographs taken, 27 of vertical (75%) and 31 of horizontal (86%) deviations were below 3 degrees. 66 % of the deviations were below 3 degrees both horizontally and vertically. The results show that the tendency for deviation is higher in the vertical than in the horizontal direction.

6.2 Errors and solutions

Many of the radiographs had quite high deviations. There are various factors that may have contributed to the final results. The x-ray unit was probably the biggest challenge during the experiment. After placement of the collimator towards the guiding ring on the film holder the x-ray unit had the tendency of moving downwards, contributing to the change of angulation and also explaining the greater deviations in the vertical than the horizontal beam angle angulation. Several factors directly related to the making of the holders had to be solved. When attaching the wire pieces onto the holders, a ruler was used to determine the site of placement, both before and after attachment to ensure that correct distance had been obtained. This could have been done more accurately using a calliper. Furthermore an orthodontic forceps was used for cutting the wires, resulting in some degree of deformation of the pieces, and creating difficulties finding the centre of the wires on the image. This could affect the measuring of the distances in the next stage. With a more suited instrument, one could accomplish a more correct shape of the wires, making it easier to distinguish the two different shaped wires, and also determine the endpoints and thus the centre. The impression material (A-silicon) used is highly dimension stabile, but its elasticity may allow some degree of distortion when taking the radiographs. This could happen if the collimator touches the holder, and thereby alters its original orientation. The holder itself has some flexibility and the plastic aiming device coupled with the holder is not a completely stabile device all together and it bends easily. As mentioned the collimator has the tendency of moving in a vertical downwards direction after being positioned, probably as a result of gravity. This slightly bends the whole construction and might contribute to the higher deviance in the vertical than the horizontal direction. Important prerequisites for the material used for the occlusal index are short setting time (less than a couple of minutes), easy manipulation, strong adherence to holders, radiolucency and having a dimension stable shape over time, without tendency for fracture. Elastic impression materials are generally divided into two groups, elastomeric and hydrocolloids (Giordano 2000). Hydrocolloids can be both reversible and irreversible (alginates). They have low dimension stability due to quick evaporation of water. Elastomers include polysulphides, condensation or addition silicones and polyether. Polysulphide and condensation silicones are not dimension stable. Addition silicones are dimension stable because no leftover product forms with setting. The same goes for polyether. Some impression materials were unacceptable right from the start as regards to their properties. It was decided to use addition silicones because of the highly dimension stable properties of this material. After testing several different ones Flexitime Correct Flow was chosen as most suitable. Duckworth et al. (1983) used polyether as their material of choice. These two different materials have much of the same properties. Furthermore the process of taking the radiographs is dependent of the clinician performing the task, but just how much is difficult to say. The entire idea of constructing standardized holders is of course to minimize this factor, but it is difficult to entirely exclude it. In a study by Rudolph and White (1988) the average operator alignment error was found to make a substantial contribution to total variation in positioning. For the combinations (film holder and impression material) of the standardized film holders the alignment variations were due to operator errors in 71.1% of cases, whereas material distortion contributed in 28.9% of cases. In this study such calculations were not performed, but it is likely that operator error factors contribute to the variations to a large degree. A more stable collimator and a film holder of a more rigid material are desirable, but would maybe make it less clinically applicable seeing as the systems used are very commercially available. A more rigid holder would possibly make the holder more uncomfortable for the patient. In other studies a design with a coupled film holder and collimator was used, but this has to a large degree been excluded because of its unpractical design. This conclusion was made already in the study of Duckworth et al.

(1983). Determining the centre and endpoints of the markers on the radiographs can vary depending on the person performing the task. Even though precautions were taken, using an average between two independent measurements performed by two clinicians, one cannot exclude systematic errors. The radiographs were interpreted in Digora, enlarging and calibrating them based on the known 10 mm length of the horizontal wire. The measuring tool in Digora was used to determine the distance between the midpoints of the two round and rectangular wires. Drawing up this line was done manually on the computer screen, not by the help of any program that probably would have made the measurements more accurate. Calibrations of measurements between the two performers were done and show there is no significant difference in them. Measuring of the deviances is vulnerable when deciding the centre and distances between the wire pieces. When dealing with such small distances, small errors in one of the mentioned stages can easily lead to a set of radiographs being deemed as outside desired values. Furthermore some of the radiographic pairs showed quite high deviations compared to the majority of images. The total number of radiographs represents a rather small selection, consisting of only 36 images. Consequently the mean values are affected and might give a wrong impression. Using these holders in a clinical setting might be very different from using them on phantom heads. Especially in cases with periodontitis, the patient dentition might change between visits. On the other hand, real patients might be able to report if the occlusion doesn't "feel right" (Rudolph and White 1988). Eickholz et al. (1998) reported that many of their radiographs were not suited for the subtraction technique. One of the main reasons for this was unstable support of the film-holding device in edentulous areas. The technique requires some extra time and effort compared to taking non-standardized radiographs. The procedure needs to be explained to the patient, and maybe even practiced a couple of times. The technique is also more time consuming than taking ordinary radiographs due to the setting time of the impression material.

6.3 Previous work

Duckworth et al. (1983) showed an average horizontal angulation error of 1.25 ± 0.93 degrees while vertical angulation errors varied with an average of 2.39 ± 2.23

degrees. The authors concluded that the angular variations were within acceptable limits for this type of analysis as reported by Ruttiman et al. (1982) without providing what these numbers actually were. Schulz et al. (1991) also based their construction of radiographic film-holders on Duckworth et al. (1983). In 63% of radiographic comparisons, the angular deviation of the central rays between the serial exposures was below 0.9 degrees. They concluded that utilization of this type of device could provide radiographs of sufficient quality to allow their use in image subtraction. Duckworth et al. (1983) have been criticized for not being accurate enough in their measurements. It is pointed out in the paper by Wu et al. (2005) that two kinds of error can occur in the process of applying these standardized film holders. First of all the improper orientation of the central beam against the guiding device and secondly due to improper seating of the bite block against the teeth in question. They mention that many studies have failed to address either of these errors and that they have just focused on the central beam deviation. Wu et al. (2005) and Rudolph and White (1988) conclude that the best and most useful way to measure radiographic standardization is to use alignment markers, but point out that Duckworth et al. (1983) had placed the markers on the bite block. When the markers are placed this way distortion of the placement of the bite block against the teeth will not be revealed as angulation errors. To eliminate this error they decided to place the markers rather on the teeth, separating them buccolingually. They do not, however, mention how this could be transferred to a clinical real-life situation. The main goal of Wu et al. (2005) was to develop a prototype of film holders to take standardized intraoral radiographs that are not cumbersome and time consuming and require extensive fabrication. These authors suggested that the use of impression materials should be avoided since it requires disinfection, can easily separate from the bite block and can be exposed to distortion and deterioration over time. They therefore suggested the use of a coordination grid and concluded that this was just as effective as an occlusal index consisting of an impression material. Using this coordination grid sets higher demands on the practitioner in recording and repositioning the contact points.

6.4 Subtraction radiography

In this study 66 % of the image pairs have deviations below 3 degrees. Further 3 image pairs have values just above 3 degrees (≤3.14 degrees). According to a study by Rudolph et al. (1987) who tested the usefulness of digital subtraction radiography (DSR) it was concluded that with geometric errors below 3 degrees it is possible to recognize thickness changes of 0.42 mm in 100 % of the cases. Optimally the deviation should not exceed 0.9 degrees to be able to detect changes as small as 0.12 mm in cortical bone. Variations in projection geometry have a detrimental effect on the quality of the radiograph. This effect progresses with increasing deviation. However, even with images deviating as much as 8-9 degrees alterations in bone are easier detected with subtraction techniques, than with conventional visual inspection (Rudolph et al. 1987). The number of artefacts on subtraction images, as judged by Gröndahl et al. (1984), is too high with deviations beyond 6 degrees and they decided to discard all images above this value. In the study by Ruttimann et al. (1982) the goal is to describe the method of digital subtraction radiography and show its clinical and diagnostic potential. The usefulness of subtraction radiography is clearly identified by showing that 72.8±9.1% of the lesions was discovered with conventional viewing, as compared to 93.8±1.9% by subtraction technique. Gröndahl et al. (1984) found the same tendency in their study. Hausmann et al. (1991) claimed that for correct diagnosis on a subtraction radiographs deviations should not exceed 2 degrees. Ideally the angulation difference should be 0 degrees seeing as correct interpretation drops drastically from 97-99% in cases with zero degrees variation, compared to 68-87% degrees with variations of 2 degrees. They note that earlier investigators have concluded that 2 degrees is an adequate value for this purpose, but criticize them for making defects in alveolar bone that do not simulate real-life periodontal lesions and basing their values on this. These lesions are easier to discriminate from structural noise since they have sharp edges. A real periodontal lesion has more diffuse borders and will therefore be mistaken for structural noise more easily. When monitoring infrabony lesions there are small areas of interest. The structural noise regarding the entire radiograph might not be of crucial importance. The entire area of the radiographs does not have to correspond, but the small area of interest can be fitted so that they overlap better. Thus the structural noise of this area is decreased. In this study, when comparing the images with deviations slightly below 3 degrees and down to less than 1 degree, we see a marked difference in how they match each other, and 2 degrees stands out as an acceptable limit, as the deviation looks minimal when they are subtracted. These findings can be used when radiographs are taken of patients in the clinic. By calculating the deviation between the two wires, one can decide whether or not it is reasonable to compare the follow-up radiograph considering bone regeneration. A way of making the system even more clinically acceptable would be to have a standard table where distances between wires are listed with their corresponding degrees. This way it would be easy for a clinician to check and assess if a radiograph is of sufficient quality to be used in subtraction radiography.

6.5 Clinical relevance

So what is the purpose of developing these holders? By perfecting this system it has the potential for being a great tool for detecting mineralization alterations in bone at an early stage. Once periodontitis is diagnosed changes in bone levels and density can accurately be monitored if the radiographs have identical angulations or minimal angular deviations. With the development of DSR the need for radiographs with identical anatomical location and projection geometry is absolutely necessary. With DSR subtle changes may be found at an early stage and one will be able to better evaluate the effect of treatment. Also, as already mentioned, the system will make it easier for clinicians to decide if a follow-up radiograph they have taken lie within acceptable limits, or if a new radiograph should be taken immediately. Normally when assessing the status of a periodontally compromised patient a full status radiographic examination is conducted. This full status consists of 18 images, 14 periapical and 4 bitewing radiographs. The disadvantage of periapical images is that they are not reliable in evaluating horizontal bone levels and this is the reason for also taking bitewings. The vertical holders have the advantage of better showing the horizontal levels and can in addition be used to diagnose caries lesions. Furthermore, the film can be pushed further down if bone levels or infrabony lesions are more apically placed. In our study we have only taken radiographs in the posterior part of the dentition, but the vertical holders can be used also in the anterior region, as done in other studies (Duckworth et al. 1983). Consequently, in our method, a full periodontal and caries assessment can be made out of only 7 vertical bitewings, thereby drastically reducing patient radiation levels.

6.6 Future developments

To determine the importance of angular differences, measuring bone levels on pairs of radiographs should be done and be related to the vertical and horizontal angulation errors. Measuring bone levels intrasurgically has been claimed as the gold standard (Eickholz and Hausmann 2000) but since periodontal probes with at best 1-mm markings are used, measurement precision may be regarded insufficient. With the use of linear measurements on radiographs there was a tendency to underestimate bone loss compared to measuring in surgery (Eickholz and Hausmann 2000). An important element that influences the variance between the radiographic and surgical approach is the height of the bony lesion and the angular error in the radiograph (Eickholz and Hausmann 2000). Both horizontal and vertical deviations influence the measured distance between the alveolar crest and the cementoenamel junction (CEJ) on radiographs, but the effect on the distance between the CEJ and the bony defect is mainly due to variations in the horizontal angle. Underestimation of bone loss increases progressively with an increasing deviance in the horizontal angle (Eickholz et al. 1998). With an increasing horizontal angulation the bottom of the bony defect is presented as less clear, due to the overlapping of adjacent bone or tooth structure. This may lead to a measurement that deviates from the real size of the lesion (Wolf et al. 2001). Due to time constraint measuring of bone levels was not performed in this study. This being a pilot study, many adjustments can be made to improve the holders. Regarding all the sources of error and the limitations of this study, it is realistic to say that one can modify vertical bitewing holders in the digital x-ray system to meet the criteria set in this study.

7 Conclusion

The main goal of this study was to develop a prototype of a standardized and individualized radiographic holder that can be used on routine basis with minimal effort in clinic. The process of developing these holders is time consuming, but it is easily done with the right instructions and if the materials used are easily accessible. Some improvements can be done and are mentioned in the discussion part. With regards to the angular variations on radiographic pairs, the threshold acceptable for utilizing the subtraction technique was decided. This was done by first measuring and calculating the angles according to the standardized wire marks. Radiographic pairs with known angels where then superimposed and the digital subtraction technique was used to find pairs with enough elimination of structural noise. Based on this a limit of acceptance of 2 degrees was set. By knowing which distances correspond to which degrees the technique can easily be used in a clinical setting. This way radiographs deviating beyond 2 degrees can be identified simply by measuring the distance.

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Appendix

Tables A1 and A2 display the measurements for observer 1 and observer 2 respectively. Positive values represent deviations of the x-ray beam in the same directions in the primary and follow up radiograph, while the negative values represents deviations in an opposite direction to each other.

Table A1 Horizontal (H) and vertical (V) distances (mm) between squared and round orthodontic wire, and calculated deviation between subsequent exposures as measured by observer 1

Head 1						
x-ray taken in region	Distance on radiograph 1	Distance on radiograph 2	Distance on radiograph 3	Deviation 1 vs.2	Deviation 1 vs.3	Deviation 2 vs. 3
Right Molar	H:0.1	H:0	H:0.2	H:0.1	H: 0.1	H:0.2
	V:0.8	V:0	V:0.1	V:0.8	V:0.7	V:0.1
Left Molar	H:0.2	H:0.6	H:0	H:0.4	H:0.2	H:0.6
	V:1.3	V:0.5	V:1.8	V:0.8	V:0.5	V:1.3
Right Premolar	H:0.3	H:0.6	H:0.5	H:0.3	H:0.2	H:0.1
	V:0.2	V:0	V:0.2	V:0.2	V:0	V:0.2
Left Premolar	H:0.2	H:0.2	H:0.1	H:0	H:0.1	H:0.1
	V:0.3	V:0.8	V:0.2	V:0.5	V:0.1	V:0.6
Head 2						
x-ray taken in region	Distance on radiograph 1	Distance on radiograph 2	Distance on radiograph 3	Deviation 1 vs. 2	Deviation 1 vs.2	Deviation 2 vs. 3
Right Molar	H:0	H:0.2	H:0.4	H:0.2	H:0.4	H:0.2
	V:1	V:0.6	V:0.3	V:0.4	V:0.8	V:0.3
Left Molar	H:0.4	H:0.2	H:0.8	H:0.1	H:0.4	H:0.6
	V:0.9	V:1	V:0.5	V:0.1	V:0.4	V:0.5
Right Premolar	H:0.2	H:-0.6	H:0.2	H:0.8	H:0	H:0.8
	V:0.6	V:0.1	V:-0.5	V:0.5	V:1.1	V:0.6
Left Premolar	H:0.2	H:0.5	H:0.8	H:0.3	H:0.7	H:0.3
	V:0.7	V:0.5	V:0.8	V:0.3	V:0.1	V:0.3
Head 3						
x-ray taken in region	Distance on radiograph 1	Distance on radiograph 2	Distance on radiograph 3	Deviation 1 vs. 2	Deviation 1 vs. 3	Deviation 2 vs. 3
Right Molar	H:-0.2	H:0	H:0.2	H:0.2	H:0.4	H:0.2
	V:0.8	V:0.3	V:0.5	V:0.5	V:0.3	V:0.2
Left Molar	H:0.3	H:0.5	H:0.3	H:0.2	H:0	H:0.2
	V:0.2	V:0.3	V:0	V:0.1	V:0.2	V:0.3
Right Premolar	H:0.1	H:0	H:0.2	H:0.1	H:0.1	H:0.2
	V:0.5	V:0	V:0.3	V:0.5	V:0.2	V:0.3
Left Premolar	H:0.3	H:0.5	H:0.6	H:0.2	H:0.3	H:0.1
	V:0.2	V:0.5	V:0.2	V:0.3	V:0	V:0.3

Table A2 Horizontal (H) and vertical (V) distances (mm) between squared and round orthodontic wire, and calculated deviation between subsequent exposures as measured by observer 2

Head 1						
x-ray taken in region	Distance on radiograph 1	Distance on radiograph 2	Distance on radiograph 3	Deviation 1 vs.2	Deviation 1 vs. 3	Deviation 2 vs. 3
Right Molar	H:0.1	H:0	H:0.2	H:0.1	H: 0.1	H:0.2
	V:0.8	V:0	V:0.1	V:0.8	V:0.7	V:0.1
Left Molar	H:0.2	H:0.6	H:0	H:0.4	H:0.2	H:0.6
	V:1.3	V:0.5	V:1.9	V:0.8	V:0.6	V:1.4
Right Premolar	H:0.3	H:0.6	H:0.5	H:0.3	H:0.2	H:0.1
	V:0.3	V:0	V:0.2	V:0.3	V:0.1	V:0.2
Left Premolar	H:0.2	H:0.3	H:0.2	H:0.1	H:0	H:0.1
	V:0.3	V:0.8	V:0.3	V:0.5	V:0	V:0.5
Head 2						
x-ray taken in region	Distance on radiograph 1	Distance on radiograph 2	Distance on radiograph 3	Deviation 1 vs. 2	Deviation 1 vs. 3	Deviation 2 vs. 3
Right Molar	H:0	H:0.2	H:0.5	H:0.2	H:0.5	H:0.3
	V:0.9	V:0.6	V:0.2	V:0.3	V:0.8	V:0.4
Left Molar	H:0.5	H:0.3	H:0.8	H:0.2	H:0.3	H:0.5
	V:0.8	V: 1	V:0.5	V:0.2	V:0.3	V:0.5
Right Premolar	H:0.2	H:-0.5	H:0.2	H:0.7	H:0	H:0.7
	V:0.5	V:0	V:-0.5	V:0.5	V:1	V:0.5
Left Premolar	H:0.2	H:0.5	H:0.9	H:0.3	H:0.7	H:0.4
	V:0.7	V:0.4	V:0.7	V:0.3	V:0.1	V:0.3
Head 3						
x-ray taken in region	Distance on radiograph 1	Distance on radiograph 2	Distance on radiograph 3	Deviation 1 vs. 2	Deviation 1 vs. 3	Deviation 2 vs. 3
Right Molar	H:-0.1	H:0	H:0.2	H:0.1	H:0.3	H:0.2
	V:0.8	V:0.3	V:0.5	V:0.5	V:0.3	V:0.2
Left Molar	H:0.4	H:0.5	H:0.3	H:0.1	H:0.1	H:0.2
	V:0.2	V:0.3	V:0.1	V:0.1	V:0.1	V:0.4
Right Premolar	H:0.2	H:0	H:0.3	H:0.2	H:0.1	H:0.3
	V:0.4	V:0	V:0.3	V:0.4	V:0.1	V:0.3
Left Premolar	H:0.2	H:0.5	H:0.6	H:0.3	H:0.4	H:0.1
	V:0.2	V:0.5	V:0.3	V:0.3	V:0.1	V:0.2

The average of the calculated deviations is presented in Table A3. The deviation values are given in both millimeters and the corresponding degrees.

Table A3 Average values of calculations done by observer 1 and observer 2

Images	Vertical Deviations (degrees)	Vertical deviations(mm.)		Horizontal deviations(mm.)	Horizontal Deviations (degrees)
1 vs. 2	4.57	0.8	Head 1 Right Molar	0.1	0.57
1 vs. 3	4	0.7		0.1	0.57
2 vs. 3	0.57	0.1		0.2	1.14
1 vs. 2	4.57	0.8	Head 1 Left Molar	0.4	2.29
1 vs. 3	3.14	0.55		0.2	1.14
2 vs. 3	7.68	1.35		0.6	3.43
1 vs. 2	1.43	0.25	Head 1 Right Premolar	0.3	1.71
1 vs. 3	0.28	0.05		0.2	1.14
2 vs. 3	1.14	0.2		0.1	0.57
1 vs. 2	2.86	0.5	Head 1 Left Premolar	0.05	0.28
1 vs. 3	0.28	0.05		0.05	0.28
2 vs. 3	3.14	0.55		0.1	0.57
1 vs. 2	2	0.35	Head 2 Right Molar	0.2	1.14
1 vs. 3	4.57	0.8		0.45	2.57
2 vs. 3	2	0.35		0.25	1.43
1 vs. 2	0.85	0.15	Head 2 Left Molar	0.15	0.85
1 vs. 3	2	0.35		0.35	2
2 vs. 3	2,86	0.5		0.55	3.14
1 vs. 2	2.86	0.5	Head 2 Right Premolar	0.75	4.28
1 vs. 3	5.99	1.05		0	0
2 vs. 3	3.14	0.55		0.75	4.28
1 vs. 2	1.71	0.3	Head 2 Left Premolar	0.3	1.71
1 vs. 3	0.57	0.1		0.7	4
2 vs. 3	2	0.35		0.3	1.71
1 vs. 2	2.86	0.5	Head 3 Right Molar	0.15	0.85
1 vs. 3	1.71	0.3		0.35	2
2 vs. 3	1.14	0.2		0.2	1.14
1 vs. 2	0.57	0.1	Head 3 Left Molar	0.15	0.85
1 vs. 3	0.85	0.15		0.05	0.28
2 vs. 3	2	0.35		0.2	1.14
1 vs. 2	2.57	0.45	Head 3 Right Premolar	0.15	0.85
1 vs. 3	0.85	0.15		0.1	0.57
2 vs. 3	1.71	0.3		0.25	1.43
1 vs. 2	1.71	0.3	Head 3 Left Premolar	0.25	1.43
1 vs. 3	0.28	0.05		0.35	2
2 vs. 3	1.43	0.25		0.1	0.57

The distribution of deviations when comparing radiographs is illustrated in Fig. A1 and A2, vertical and horizontal deviations respectively.

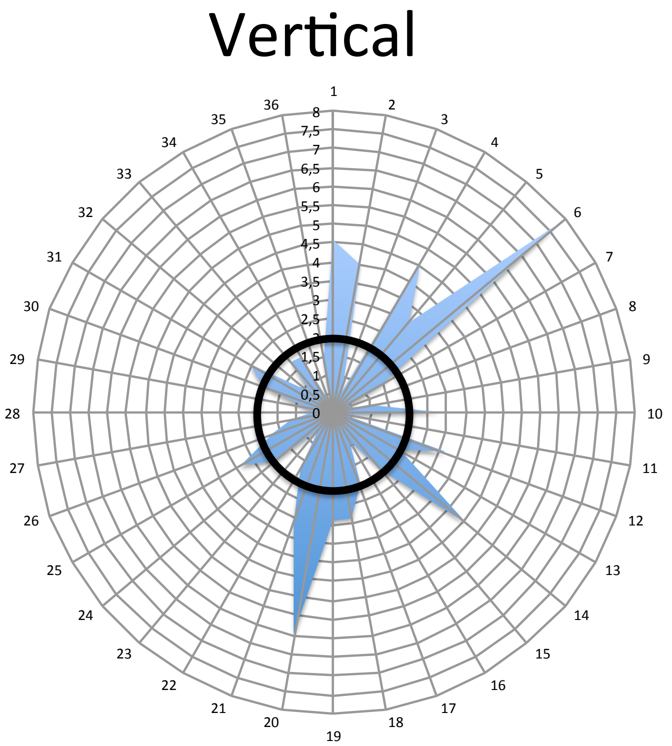

Fig. A1 Distribution of the deviation when comparing radiographs taken in the same region. The limit of 2 degrees is highlighted

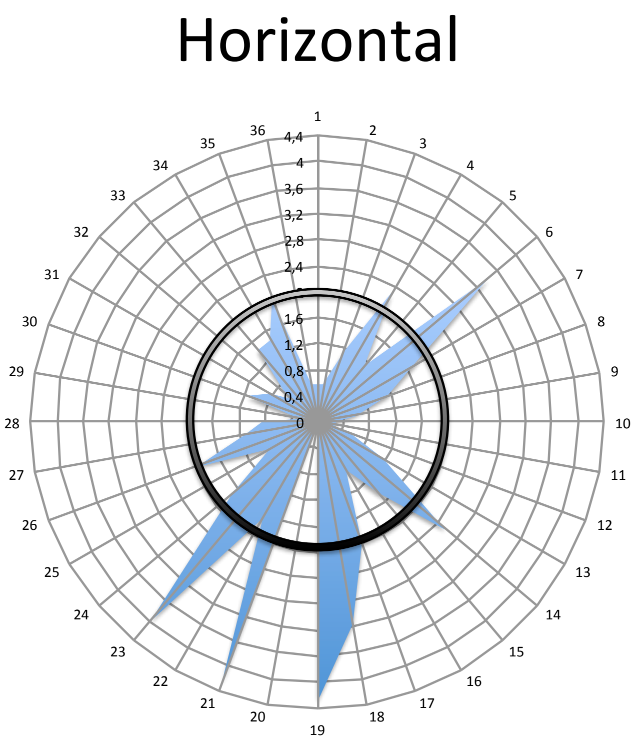

Fig. A2 Distribution of the deviation when comparing radiographs taken in the same region. The limit of 2 degrees is highlighted