Clinical Validation of a New Subtraction Radiography Technique for Periodontal Bone Loss Detection

Pirkka V. Nummikoski,* Bjorn Steffensen,† Kathy Hamilton,‡ and S. Brent Dove*

Background: Diagnostic subtraction radiography (DSR) is a new digital radiographic image subtraction method designed to enhance detection of crestal or periapical bone density changes and to help evaluate caries progression in teeth. In this clinical study, the performance of the DSR method was evaluated for its ability to detect periodontal bone loss and was compared with that of conventional evaluation of radiographs and the standardized cephalostat-guided image acquisition and subtraction technique (LRA) which served as the “gold standard.”

Methods: In each of 25 subjects with alveolar crestal bone loss created by periodontal surgery, one set of DSR radiographs and one set of LRA radiographs were obtained before and after the surgery. Subtraction images were then generated by both the proprietary DSR and the LRA techniques. Four viewers evaluated the paired film sets and both subtraction image sets using a 5 point confidence scale to determine the presence or absence of crestal bone loss. Receiver operating characteristics (ROC) statistical procedures were applied to analyze the diagnostic accuracy and statistical differences between the three imaging modalities.

Results: The DSR subtraction viewing generated an ROC area of 0.882. For 2 of the viewers this represented a statistically significant gain ($P < 0.05$) over the conventional viewing of the radiographs which had an average ROC area of 0.730. In comparison, the LRA method achieved an area of 0.954. The differences between the LRA and the DSR subtraction methods were not statistically significant, but the statistical power for claiming equality was low ranging from 0.2 to 0.6.

Conclusions: The use of the DSR technique in clinical radiographic image acquisition and subsequent subtraction analysis clearly enhanced the accuracy of alveolar crestal bone loss detection when compared to conventional film viewing. Because this methodology is less resource demanding than LRA and the film exposure techniques and computer-based image analysis skills may be acquired with only a few hours of training, the DSR has potential in clinical practice. J Periodontol 2000;71:598-605.

KEY WORDS
Radiography, dental; digital; bone loss/diagnosis; bone loss/radiography; radiography, subtraction.

Early detection of periodontal bone loss is important because it provides the clinician with the basis for applying preventive or corrective measures. Reduction of alveolar crestal bone density is one early sign of periodontal disease and precedes the loss of height of the alveolar crest. However, small changes in density cannot be reliably detected by conventional comparison of radiographs due to great variations in the anatomical structure and radiographic image density and contrast. Subtraction radiography is a technique that facilitates both qualitative and quantitative visualization of even minor density changes in bone by removing the unchanged anatomical structures from the image. This enhances the detection of bone structures with true density change, and significantly improves the sensitivity and accuracy of the evaluation. One disadvantage of digital subtraction radiography techniques, as used presently, is the need for close to identical projection alignment during the exposure of the sequential radiographs. Furthermore, highly specialized computer image processing equipment and software is required for image analyses.

To address the need for reproducible positioning of the radiographs, 2 main techniques have been developed, one based on customized occlusal stents and one utilizing a cephalostat. The occlusal stents made of cold-cure acrylic or impression materials align the films reproducibly to the dentition and, with careful application, the stent method is feasible for limited numbers of patients and follow-up periods that do not exceed 2 years. This time limitation is due to the tooth movements over time that ulti-
mately result in inadequate fit of the stents. To alleviate this problem, Jeffcoat and associates introduced a projection standardization method that combines a cephalometric head positioning device and a long source-to-object distance. However, this method is not feasible in most conventional dental practices due to the requirement for specialized positioning equipment.

With the progress in processing capability of personal computers, development of software-based image alignment and density matching programs has been central to recent efforts to transform subtraction radiography into a technique that is also feasible for clinical practice. Whereas image density and contrast matching problems have been addressed successfully by computer algorithms, the correction for projection-based discrepancies has posed a much more complicated problem to solve and several attempts have had only limited success. Reference point methods utilizing 4 defined points in the image can correct linear discrepancies resulting from the film tilt, but higher order quadratic polynomial functions and at least 9 reference points are needed to correct more complex image distortions such as those due to film bending. Generally, these algorithms are only capable of correcting image distortions from projection variations within 1 to 5 degrees.

Recently, Lehmann and colleagues devised and tested a perspective projection-based model for image alignment combined with additional computerized methods to improve matching of the reference points. This approach aligned the sequential images adequately when the remaining subtraction image noise was used as the criteria. In addition, the method was independent of the accuracy of viewer’s reference point determination and marking. Dunn and associates and Ostuni et al. have designed and tested similar digital image processing algorithms for use with non-standardized radiographic images and found these to perform adequately under laboratory conditions. However, there has not yet been rigorous clinical testing to confirm the applicability and efficacy of these methods in patients.

An image analysis system, diagnostic subtraction radiography (DSR), has been developed which combines the use of a positioning device during film exposure with specialized software designed for digital image subtraction using conventional personal computers in dental offices. This image analysis software system applies an algorithm that corrects for the effects of angular alignment discrepancies and provides a high degree of flexibility in the imaging procedure. In laboratory experiments, the algorithm of the DSR was found to be capable of adjusting for up to 10° projection differences between sequential images and to perform high quality subtractions with low remaining subtraction image noise.

The clinical study reported here evaluated the DSR method and compared this new approach to conventional clinical viewing of sequential radiographs and to a well-controlled cephalostat technique.

MATERIALS AND METHODS
General Study Design
Preliminary calculations for the sample size indicated that 25 subjects would be needed to achieve statistical power of 0.8 for the study. Altogether 35 patients were recruited to achieve the sample size of 25, 10 were not enrolled for different reasons (see Results). These patients were scheduled to receive one of several periodontal surgical procedures ranging from flap-surgery for access with no alveolar bone removal to crown lengthening with reduction of alveolar bone crest height. The details of the surgical procedures undertaken were recorded but not revealed to any of the examiners. Thus, the radiographic material included cases with clear bone changes between subsequent images, as well as cases where little bone change was anticipated. The research protocol was approved by the Institutional Review Board for human subjects of the University of Texas Health Science Center at San Antonio. For the analysis, 3 sets of images were interpreted by 4 viewers: subtraction image taken and subtracted by DSR technique; subtraction images taken and subtracted by the longitudinal radiographic assessment (LRA) method; and conventional film-pairs using the same films that were taken for the DSR technique.

All the cephalostat-based radiographs were taken at the Longitudinal Radiographic Assessment Clinic, a dedicated imaging facility at the UTHSCSA Dental School equipped to produce standardized radiographic images for long-term follow-up studies. The DSR radiographs were exposed with a conventional dental x-ray unit in the Radiology Clinic of the Dental School. All films were developed using the same automatic processor following manufacturer’s instructions. For each evaluated technique, a baseline radiograph was taken immediately prior to surgery and 2 subsequent radiographs 2 weeks after surgery. By this design, the baseline film and 1 postoperative film formed the image pair that contained the surgically induced bone change, whereas pairing of the 2 postoperative radiographs represented the “no-change” corresponding to method error alone. To simulate the conditions of long-term radiographic follow-up, the patients were asked to stand up after the first exposure. The unit was then zeroed, and the patient seated again for the second exposure using recorded settings.

Four dentists were asked to review the images and score the visual changes for evaluation of changes

§ Electro Medical Systems, Richardson, TX.
|| Dent-X Co., Elmsford, NY.
between recorded images. For these image series receiver operating characteristic (ROC) curves were generated for each observer and technique, and statistical analysis was performed to quantify the accuracy which is represented by the areas under the ROC curves.

**Image Acquisition, Alignment, Digitization, and Subtraction**

**DSR method.** The DSR radiographs were taken over a period of 4 months by 1 dental assistant and 2 radiology technicians assigned to the radiology clinic service. The exposures were performed with a conventional dental x-ray unit equipped with a 40 cm long cone and using 0.4 second exposure time at 15 mA and 70kVp. Intraoral film was positioned in the area of interest using the DSR aiming device equipped with an additional beam collimator support that assists in beam alignment. The radiographs were digitized by scanning in the DSR high resolution scanner and saved as 580 by 440 pixel images with an 8-bit gray scale range. The acquired digital images of the pre-and post-surgical films were then aligned and subtracted in a computer by a dentist (KH) familiar with the DSR alignment procedure.

**Longitudinal Radiographic Assessment Method**

Intraoral films were taken of the area of interest using a film-holding bite block. The projection geometry between the baseline and follow-up radiographs was standardized by stabilizing the patient’s head in a cephalostat and recording the head position in horizontal and vertical directions. The films were exposed using a medical x-ray unit equipped with a rotating anode tubehead. Exposure parameters were 65 kVp, 150 mA, 0.30 second, and 150 cm focus-to-film distance. The radiographs were converted to 640 by 480 pixel digital images with 8-bit gray scale range using a video camera interfaced with a framegrabber. The baseline and follow-up radiographs were aligned with a real-time subtraction program, digitized, and saved in the computer for analysis using algorithms included in the computer-assisted radiographic evaluation software package. For the image subtraction, background differences in overall distribution of gray level values between baseline and the follow-up radiographs were adjusted by a non-parametric histogram matching algorithm.

**Analysis of Subtraction Images and Conventional Radiographs**

ROC analysis was the method of choice for the clinical validation of the DSR system. This analysis eliminates the contribution of observer bias and variations in individual perception by comparing the diagnoses of the observer to the known state of disease. Thereby this index of accuracy estimates the inherent capability of the imaging system to show the disease status and is independent of the criteria adapted for making particular decisions. The use of images that are taken from the same patients increases the statistical sensitivity of the analysis by taking into account the correlation that exists between the images taken from the same location.

**Data Analysis**

The statistical analysis of the acquired data was performed using a ROC analysis program designed for categorical same-case type response data. The ROC areas of the films and both subtraction methods were calculated separately for each viewer, and the differences between the methods were determined at the P <0.05 significance level. To initially determine the sample size, a clinically significant difference was considered if there was a difference in the ROC areas between the different imaging modalities of at least 0.100. Accounting also for the expected correlated nature of the data (r >0.70) and the magnitude of the standard deviations, as established in previous studies...
ies, a sample size of 24 image pairs was found to be adequate to achieve statistical power of 0.8.

RESULTS
Thirty-five patients were recruited for the study, but the radiographs from 10 were not suitable for analysis due to technical errors in 1 of the 2 methods resulting from overexposure, extensive angulation errors, or positioning errors with images not containing all of the surgery area. Four of the films were rejected due to errors in the LRA technique and 6 due to errors in DSR technique. Among the 25 accepted radiographs, the surgical site was in the maxillary arch in 10 patients and in the mandibular arch in the other 15. Figure 1 presents a series of baseline and follow-up radiographs exposed with DSR method (Fig. 1A and 1B). Following DSR subtraction (Fig. 1C), the bone loss is displayed clearly as dark gray areas in the crestal bone between the molars.

Figure 1.
Representative set of images exposed with the DSR method showing the baseline (A) and follow-up (B) radiographs used to generate the subtraction image (C). The extent of the change in the interdental alveolar bone is visualized better by the subtraction image than by conventional comparison of the radiographs.

Figure 2 shows the ROC curves that the 4 viewers obtained from the evaluation of the conventional radiographs and subtraction images produced by the DSR and the LRA techniques. Table 1 lists the areas under these curves, their averages, and the $P$ values of the differences between the conventional evaluation of the films and evaluation of subtraction images. As detailed in Figure 2 and Table 1, conventional evaluation of radiographs achieved ROC areas ranging from 0.670 to 0.811 while evaluation of the DSR subtractions of the same images generated areas ranging from 0.842 to 0.911. This improvement in accuracy was statistically significant ($P<0.05$) for 2 of the 4 raters. When the viewing of the conventional radiographic films exposed by LRA or DSR methods were compared, the viewers scored the changes more accurately on LRA radiographs, but these differences were not statistically significant (Table 1).

Figure 2.
ROC curves achieved by the 4 viewers. The areas under each ROC curve are presented in Table 1.
No statistical differences were found between evaluation of images obtained by the DSR subtraction method and the “gold standard” LRA subtraction technique (Table 2), although the LRA method attained somewhat larger ROC areas with each rater. The statistical power (1-β) in these comparisons was rather low with 0.17, 0.42, 0.24, and 0.32 for rater 1, 2, 3, and 4, respectively, indicating that there still may be a true difference between the two methods. The Kendall Tau correlation coefficients of the scores between the DSR and LRA imaging modalities ranged from 0.2 to 0.6, indicating a lower correlation between diagnostic calls than was expected.

A separate analysis of the DSR subtraction images compared maxillary and mandibular surgery sites. The accuracy of evaluating mandibular cases was higher with an ROC curve area of 0.894, compared to 0.852 for the maxillary sites. This difference was not statistically significant.

Finally, to gain an estimate for the clinical significance for the performance of the DSR subtraction images over conventional evaluation of radiographs, the sensitivity levels of the 2 methods were plotted at the 90% specificity level as shown in Figure 3. The corresponding sensitivity levels for each rater are listed with an ROC curve area of 0.894, compared to 0.852 for the maxillary sites. This difference was not statistically significant.

Finally, to gain an estimate for the clinical significance for the performance of the DSR subtraction images over conventional evaluation of radiographs, the sensitivity levels of the 2 methods were plotted at the 90% specificity level as shown in Figure 3. The corresponding sensitivity levels for each rater are listed

![Figure 3. ROC curves generated from conventional film evaluation and DSR subtraction images for viewer 3. The plotted line corresponds to the 90% specificity level. At this specificity level, the sensitivity was 0.268 for the conventional film evaluation and 0.769 for the DSR subtraction method.](image)

<table>
<thead>
<tr>
<th>Viewer</th>
<th>Conventional Film</th>
<th>DSR Subtraction</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.547</td>
<td>0.696</td>
<td>0.149</td>
</tr>
<tr>
<td>2</td>
<td>0.394</td>
<td>0.776</td>
<td>0.382</td>
</tr>
<tr>
<td>3</td>
<td>0.268</td>
<td>0.769</td>
<td>0.501</td>
</tr>
<tr>
<td>4</td>
<td>0.394</td>
<td>0.654</td>
<td>0.260</td>
</tr>
<tr>
<td>Average</td>
<td>0.401</td>
<td>0.724</td>
<td>0.323</td>
</tr>
</tbody>
</table>

Table 1.

<table>
<thead>
<tr>
<th>Imaging Modality/Viewer</th>
<th>Conventional Film Evaluation</th>
<th>Subtraction Image Evaluation</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.811 0.063</td>
<td>0.911 0.044</td>
<td>0.132</td>
</tr>
<tr>
<td>2</td>
<td>0.670 0.080</td>
<td>0.842 0.064</td>
<td>0.049</td>
</tr>
<tr>
<td>3</td>
<td>0.704 0.076</td>
<td>0.892 0.050</td>
<td>0.043</td>
</tr>
<tr>
<td>4</td>
<td>0.733 0.074</td>
<td>0.883 0.049</td>
<td>0.089</td>
</tr>
<tr>
<td>LRA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.875 0.057</td>
<td>0.954 0.029</td>
<td>0.312</td>
</tr>
<tr>
<td>2</td>
<td>0.856 0.057</td>
<td>0.952 0.031</td>
<td>0.100</td>
</tr>
<tr>
<td>3</td>
<td>0.843 0.051</td>
<td>0.943 0.047</td>
<td>0.061</td>
</tr>
<tr>
<td>4</td>
<td>0.879 0.050</td>
<td>0.954 0.032</td>
<td>0.166</td>
</tr>
</tbody>
</table>

Table 2.

<table>
<thead>
<tr>
<th>Viewer</th>
<th>DSR Subtraction</th>
<th>LRA Subtraction</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.911 0.044</td>
<td>0.954 0.029</td>
<td>0.408</td>
</tr>
<tr>
<td>2</td>
<td>0.842 0.064</td>
<td>0.952 0.031</td>
<td>0.051</td>
</tr>
<tr>
<td>3</td>
<td>0.892 0.050</td>
<td>0.943 0.047</td>
<td>0.465</td>
</tr>
<tr>
<td>4</td>
<td>0.883 0.049</td>
<td>0.954 0.032</td>
<td>0.164</td>
</tr>
</tbody>
</table>

Table 3.

ROC Curve Areas and Standard Deviations (SD) of Conventional Films and Subtraction Images

ROC Curve Areas and Standard Deviations (SD) Derived From the Subtraction Images Generated
in Table 3. There was constant and considerable improvement in sensitivity by using the DSR subtraction method with an average sensitivity increase from 0.40 to 0.72 at the 90% specificity level.

**DISCUSSION**

A new digital radiographic image subtraction method, DSR, was evaluated under clinical conditions. The results indicate that the DSR method provides a significantly improved accuracy for detection of periodontal bone loss over the conventional viewing of clinical films. DSR could, therefore, provide an important tool for detection of advancing periodontal lesions in a general practice setting.

With the DSR subtraction method, all the raters showed improvement in their diagnostic accuracy over conventional evaluation of radiographs. For 2 raters, this improvement was statistically significant. This was not an unexpected finding, because several earlier studies have established that the use of digital image subtraction increases the accuracy of periodontal bone loss detection. However, unlike those studies, in which the radiographic images were acquired under strictly controlled head positioning and exposure, the exposure of radiographs for the DSR is possible under conditions found in most dental practices. One reason for the smaller than expected difference between these modalities is that conventional radiographs in this study were exposed using the DSR instrument, thereby making them somewhat more standardized than truly non-standardized clinical periapical radiographs would have been. Another reason for 2 viewers not reaching a statistically significant difference between modalities, although the improvement was clearly evident, was the lower than expected correlation between the intra-reader readings that ranged from 0.2 to 0.6. With this level of correlation, a higher number of subjects would be needed to show statistical significance.

Comparison of the DSR to the established and highly standardized LRA method, used as a “gold standard,” showed that there was no significant difference between these 2 methods. However, because the statistical power of the study was low ranging from 0.17 to 0.42 with different viewers, we cannot claim that these methods are equal in accuracy. The diagnostic performance that the specialists achieved in this study is likely to be better than would be achieved by a general practitioner who does not possess the same experience in alignment and reading subtraction images. However, with training, the superiority of the DSR method over the conventional radiography should prevail.

The fact that 10 cases were rejected for reasons of technical errors increased the level of accuracy of all the techniques in this study because these poor quality images conceivably would have been misdiagnosed. However, these 10 discarded cases were clearly unacceptable as radiographic images. The high rate of unacceptable films, most of which were obtained in the early part of the study, indicates that adequate training must be completed by the radiographer to perform consistent imaging. The subtraction images of mandibular surgery sites were slightly better than maxillary sites, as it is more difficult to reproduce film angulations in the maxillary arch due to larger vertical variation in the bite block positioning.

Although the viewers had no knowledge of the nature of the periodontal surgery, some of the cases had lesions that were not optimal for testing differences between conventional and subtraction methods. For example, the horizontal nature of the bone loss produced by crown lengthening surgery may have allowed the viewers to visualize changes in height rather than in density thus favoring the conventional radiographic method. In addition, other evidence of surgery such as removal of calculus and recontouring of restorations could not be avoided in some cases and may have given an indication of the presence of a surgical site. Therefore, it is noteworthy that the evaluation of the DSR subtraction images yielded such a clearly improved outcome over conventional evaluation of radiographs exposed using the same DSR film holder.

To gain an appreciation for the extent of accuracy needed to improve to achieve clinical significance, the sensitivity levels were plotted from the ROC curves at the specificity level of 90%. At this high level of specificity, the gain in sensitivity was considerable when DSR subtraction was used over conventional film evaluation, leading to almost a doubling of the lesion detection frequency among the viewers (Table 3). In clinical practice such an improvement in sensitivity would be significant and would constitute the basis for an enhanced potential to intercept deterioration of periodontal sites.

**CONCLUSIONS**

The use of the DSR method for acquisition of clinical radiographs and subsequent subtraction analysis clearly enhanced the accuracy of detection of alveolar crestal bone loss compared to conventional film evaluation. This was accomplished with a few hours of training of the operator and with the use of simple projection standardization, and without use of individual stents or cephalostat devices. When compared to the well-controlled image acquisition techniques used in the LRA clinic, it is evident that further development of the x-ray beam aiming device would increase consistency of the imaging, and thereby increase the accuracy of the DSR method further.

Direct digital x-ray sensors are improving rapidly and will eventually replace radiographic film in dental
practices. Because the radiographic images acquired with these sensors are already in digital format, DSR can be readily applied for improved detection of bone loss around teeth and dental implants.36

ACKNOWLEDGMENTS

This study was supported in part by a grant from DSR/Electro Medical Systems, Richardson, Texas. Drs. Marden E. Alder, Michael A. Brunsvold, Stephen R. Matteson, and Thomas Oates, Jr. participated in the study as viewers of the conventional and subtraction images. Dr. Kathy Hamilton is the Vice President of DSR/Electro Medical Systems.

REFERENCES

31. Hanley JA, McNeil BJ. A method of comparing the
areas under receiver operating characteristic curves derived from the same cases. *Radiol* 1983;148:839-843.


Send reprint requests to: Dr. Pirkka V. Nummikoski, Department of Dental Diagnostic Science, University of Texas Health Science Center at San Antonio, 7703 Floyd Curl Dr., San Antonio, TX 78284. Fax: 210/567-3334; e-mail: nummikoski@uthscsa.edu

Accepted for publication September 27, 1999.