Clinical efficacy of a new software developed for dental digital subtraction radiography

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Objectives: The aim of this study was to test and compare the efficacy of software developed recently for digital subtraction radiography (DSR) in vivo.

Methods: An algorithm performing both manual and automated image reconstructions and contrast correction was developed for the manipulation of radiographic images. Pre- and post-operative radiographic images of ten patients were obtained and the automated subtraction analyses were performed using four different softwares (new software, Emago®, Photoshop 8.0 and Paintshop™ Pro® 9). Ten experienced dental specialists evaluated the clinical efficacy of each program and scored the softwares by using visual analogue scales (VAS). The results were statistically analysed and α was set as 0.05.

Results: The newly developed algorithm received higher scores than the others (new software = 67.89, Emago® = 64.26, Paintshop™ Pro® 9 = 33.41 and Photoshop 8.0 = 27.24, respectively). The clinical efficacies of the new software and Emago® were not significantly different (P = 0.720); likewise, Photoshop 8.0 and Paintshop™ Pro® 9 performed comparably (P = 0.295).

Conclusions: Considering this study, the new software and Emago® would be suggested for DSR in dental practice.


Keywords: radiography; digital radiography; dental; subtraction; software

Introduction

The basic concept of digital subtraction radiography (DSR) is that a meaningful comparison between two images of the same object can be made when they have the same geometric orientation and the same contrast. However, in most practical applications, discrepancies between the images occur due to some external conditions such as projection geometry, mismatches in X-ray tube settings, film developing and digitization procedures.1,2 These discordances may lead to structured noise, which, in turn, causes misinterpretation of the subtracted image.1

Many methods have been practiced to provide geometric uniformity of subsequent radiographs and to eliminate the corresponding variations in grey levels between the images.3 However, in addition to geometric standardization, further approaches are required to provide the “contrast correction” for the image which is to be subtracted from the reference image, so that contrast conflicts would not affect the resultant image.4–7 Unfortunately, current methods occasionally fail to offer the best contrast correction between the reference and test images.2

In this context, a new software was developed to be utilized for DSR, and its efficiency in image mapping and contrast correction has been demonstrated.8 However, given that the real-time effectiveness of a DSR software could be best established by clinicians in clinical conditions, this study was planned to test the efficacy of this new software in vivo and to compare it with other programs currently available/applicable for DSR.

Materials and methods

Initially, an algorithm performing automated contrast correction, vertical and horizontal alignment, and angle correction was developed to provide both manual and automated manipulation of the radiographic images.
The algorithm
The program had the functions of histogram smoothing and image warping for the standardization of the radiographic density, contrast and the geometric alignment of the images using a minimum of four reference points. Histogram smoothing was performed using an improved version of the Ruttiman’s algorithm based on smoothing the empirical distribution of the reference image by using Cardinal splines. Image warping was accomplished by affine, bilinear and biquadratic transforms.

When comparing the reference image and the modified image, a standard metric was required to measure the overall difference between the two images. For this purpose, a well known criterion that is commonly used to assess the quality of reconstructed images compared with the original ones was preferred: the peak signal to noise ratio (PSNR);  

$$PSNR = 20 \log_{10} \frac{2^d - 1}{\sqrt{\frac{1}{n} \sum_{k=1}^{n} (i_k - j_k)^2}}$$

where $d$ is the colour depth, $i_k$ and $j_k$ are the pixel intensities at position $k$ of the test and the modified images, respectively, and $n$ is the total number of pixels in the image. The more the modified image resembles the reference image, the higher the resulting PSNR value should be. For a grey scale image with $d$ bits per pixel, the typical PSNR values shall range between 20 and 40.

Initially, the nature of the study was explained to ten patients (five restorative, one surgery and four endodontic treatment cases) who were attending the Outpatient Clinic of Ege University School of Dentistry, Department of Oral Diagnosis and Radiology. The informed consent of the patients was acquired prior to their enrolment. Pre-operative and post-operative radiographs of the patients were obtained using paralleling technique with extraoral film holders (Dentsply Rinn, mpi XP, Weybridge, UK).

The exposure parameters of the X-ray device (Trophy Radiologie, 77437, Croissy-Beabourg, France) were obtained using paralleling technique with extraoral film holders (Dentsply Rinn, mpi XCP, Weybridge, UK). The subtraction functions of four different image analysis programs (Emago<sup>®</sup> (Oral Diagnostic Systems, c/o Dept. Oral Radiology/ACTA, Amsterdam, Netherlands), Photoshop 8.0 (Adobe Inc., San Jose, CA), Paintshop™ Pro<sup>®</sup> 9 (Jasc Software Inc., Minnesota, USA), and the new software developed by our team) were utilized to subtract the post-operative radiograph from the pre-operative one to produce “resultant image” of each image pair. A trained and experienced oral radiologist (SG) who had been working with these programs performed the above-mentioned process. No other interventions (such as brightness/contrast/edge enhancement, filtration, etc.) were employed either to the original images before subtraction, or to the “resultant image”.

Each patient’s pre- and post-operative radiographic image pairs and their subtracted “resultant images” were coded to provide the blindness of the study and were transported into a slide presentation (Microsoft<sup>®</sup> PowerPoint<sup>®</sup> 2000; Microsoft Corp., Istanbul, Turkey) (Figure 1). At the end, a total of 60 radiographic images (pre- and post-operative, and 4 subtracted “resultant image” by using 4 different softwares for each case) were prepared and presented to observers in a random order. In each slide, the randomization was performed by using simple random sampling designs and random numbers table.

Later, ten experienced dental specialists (three endodontists, seven oral radiologists) who were informed about the nature and contents of the study, reviewed the slide presentation under standard examination conditions. In each slide, they evaluated the programs by considering the strengths of the softwares in differentiating the radiographic changes between each original pre- and post-operative radiographic image (such as amalgam fillings, caries formation, root canal treatments, periapical bone healing, etc.). They also considered the visual acceptability of the resultant images (i.e. the uniformity of the grey colour of the final image, which represents a perfect DSR process). The observers used VAS to evaluate each program for each slide, and each program received a score between 0 to 100.

Three of the clinicians were randomly assigned to provide a second set of readings 1 week after their first observations in order to test the intraobserver agreement, and the results were analysed by application of Kappa ($\kappa$) statistics. Univariate analysis of variance (ANOVA) was used as the test method to evaluate the performance scores, and Tukey’s HSD test was used to make pair-wise comparisons between the test groups. SPSS statistical analysis program (v10.0; Chicago, IL) was utilized for statistical analyses and $\alpha$ was set as 0.05 for all tests.

Results
The overall kappa value for three randomly selected observers’ intraobserver agreement was 0.554, presenting a “moderate to fair” agreement. The overall ratings of all observers revealed that the new algorithm received the highest scores (67.89). It was followed by Emago<sup>®</sup> (64.26), Paintshop™ Pro<sup>®</sup> 9 (33.41) and Photoshop 8.0 (27.24) (Figure 2).
Tukey’s HSD test results revealed that there were no differences between the scores of the new software and Emago® (P = 0.720); and Photoshop 8.0 and Paintshop™ Pro® 9 (P = 0.295) (Table 1). However, statistically significant differences were observed between the scores of the new software and Photoshop 8.0 (P = 0.000). The same result was obtained after the evaluation of the scores of new software and Paintshop™ Pro® 9 (P = 0.000) (Table 1). This interpretation was also valid for Emago®: the differences between the scores of Emago® and Photoshop 8.0 (P = 0.000), and Emago® and Paintshop™ Pro® 9 were statistically significant (P = 0.000) (Table 1).

Figure 1  A radiographic image pair and their subtracted “resultant image” furnished as a slide presentation
This study aimed to evaluate the efficacies of four different software programs in providing the digital subtracted images of pre- and post-operative radiographs. However, other properties of the programs, such as user friendliness, magnification of the region of interest and financial costs were not determined and were excluded.

Which software program best detects a signal (dental caries, alveolar bone loss) may be accepted as important in clinical conditions; however, when a program detects a signal and presents it on the screen, it is the clinician who evaluates that image. Therefore, this study aimed to reveal which software was favoured by the clinicians, and showed that the new software and Emago were approved more than the others.

Emago is a well known software in dental radiographic image analysis. It enables arbitrary spatial filtering with user-defined masks up to $7 \times 7$ pixels in size. However, most programs not only fail to include filters and tools for image analysis and comparison, but also differ in the naming and implementation of provided functions. Photoshop 8.0 and Paintshop Pro 9 are other graphic softwares which also have subtraction options, and at least one of them has been used to obtain subtracted images. Since both programs have similar application indications, Paintshop Pro 9 may also be considered to obtain subtracted images and these four softwares were therefore included into the study. Among them, only the new software and Emago had the manual manipulation options. However, in order to provide standard and optimum test conditions, and to eliminate operator bias, all programs were operated under automated manipulation modes provided by the softwares.

Presumably, each software has its own algorithm to map the original and subsequent radiographs, and to provide contrast correction. These unique mathematical approaches result with different “peak signal to noise” ratios, and lead to resultant images which may differ from each other. In this study, the observers evaluated the resultant images provided by four softwares and scored these images on VAS, ranging between 0 and 100. During this procedure, they considered the strengths of the softwares in differentiating the radiographic changes between each original pre- and post-operative radiographic images. They also considered the visual acceptability of the resultant images produced by four softwares. So, by giving a score to each program, they also provided a ranking as well.

During the DSR procedure, a rigorous a priori standardization for aligning radiographs is not required for automatic registration methods. However, discrepancies between the radiographic image pairs still occur in clinical practice and they prevent the production of a uniform grey-coloured “resultant image” after the digital subtraction process to indicate a perfect geometric mapping and contrast correction between digital images. Therefore, the presence of black and white shadows on the “resultant image” displays the flaws in the subtraction process, originating either from the image acquisition or the algorithm of the software. Provided that all programs performed DSR on the same sets of radiographs in this study, this finding – when observed – revealed the shortcomings of the effectiveness of the algorithms. In other words, these shadows interfered with the resultant image and decreased the efficacies of the softwares in revealing the variations between the first and second

![Figure 2](image-url) The overall ratings of all observers

**Table 1** Results revealing the differences between the performance ratings of the programs

<table>
<thead>
<tr>
<th>Group I</th>
<th>Group II</th>
<th>Mean difference (I-II)</th>
<th>Sig.</th>
<th>Confidence interval</th>
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<td></td>
<td></td>
<td></td>
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radiographs. This problem was less notable with Emago® and the new software, revealing the higher accomplishments of these two programs. On the other hand, Photoshop 8.0 and Paintshop™ Pro® 9 received lower scores in this study, suggesting less adequate clinical efficacies.

The differences between the scores of Emago® and the new software were not significant, and this finding revealed the similarity of the efficacies of these programs in vivo. Even though the details of the algorithm used in Emago® are not completely lucid to the authors, it is known that softwares differ in implementation of their provided functions. Therefore, different mathematical approaches used for contrast correction and geometric standardization (which leads to different PSNRs) may be speculated as the causes of the variations between the softwares tested.

In conclusion, considering the results of this study, it may be suggested that the new software and Emago® rather than Photoshop 8.0 and Paintshop™ Pro® 9 would be proposed and preferred for DSR in dental practice.

References