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A digital subtraction radiography based tool for periodontal bone resorption analysis

Uma ferramenta baseada na radiografia de subtração digital para análise da reabsorção óssea periodontal

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Abstract

The aim of this paper was to describe an aided diagnosis scheme for periodontal bone resorption so that the dentist can make an early diagnosis of the periodontal disease and establish the best treatment plan to increase the success of healing. Three ways of displaying the results are provided: qualitative, simple quantitative and colored-percentage quantitative views. A total of 72 pairs of in vitro radiographic images were used. The main procedure registers the images perspective projection aimed to align them in rotation and translation, and is followed by the application of a contrast correction technique. The results from the subtraction were evaluated firstly by the comparison between the actual and the digital sizes corresponding to the holes made by drills in phantoms. The mean error was 4.2%. The method was also applied to actual tooth radiographic images and could detect clearly the effect of treatment of periodontal diseases. It is dependent on the reproducibility of the process of radiographs acquisition and digitization, but the calculated mean error allows to conclude its better efficacy compared to usual procedures in this field.

Keywords: computer-assisted image processing, radiography, periodontics, periodontal disease.

Resumo

O objetivo deste trabalho foi descrever um esquema de auxílio ao diagnóstico da reabsorção óssea periodontal para que o dentista possa realizar um diagnóstico prévio da doença periodontal e estabelecer o melhor plano de tratamento, de forma a melhorar o sucesso da cura. São fornecidos três modos de exibição dos resultados: visualização qualitativa, quantitativa simples e quantitativa com porcentagem colorida. Um total de 72 pares de imagens radiográficas *in vitro* foi utilizado. O principal procedimento registra a projeção perspectiva das imagens com o objetivo de alinhá-las em rotação e translação, seguido da aplicação de uma técnica de correção com contraste. Os resultados da subtração foram primeiramente avaliados pela comparação entre o tamanho atual e o digital, correspondentes aos buracos feitos pelas brocas nos simuladores radiográficos. O erro médio foi de 4,2%. O método também foi aplicado para as imagens radiográficas atuais e foi possível claramente detectar o efeito do tratamento das doenças periodontais. Tal fato depende da reprodutibilidade do processo de aquisição e digitalização das radiografias, mas o erro médio calculado permite concluir sua melhor eficácia comparada aos procedimentos usuais neste campo.

Palavras-chave: processamento de imagem assistida por computador, radiografia, periodontia, doença periodontal.

Introduction

The two most important causes of tooth loss are cavities and periodontal diseases. A large percentage of the adult population is reached by periodontal diseases that, due to their chronic and aggressive character, become the most important cause of dental extraction. The dental radiographic examination complements the clinical examination. Bone resorption diagnosis is a difficult task to be performed by dentists since it is only radiographic visible when 30% to 60% of the mineral bone content have been lost[1].

The Digital subtraction technique (DSR) is applied to solve the limitation in detecting radiographic changes. In DSR, two digital radiographic images taken at different times are subtracted so that common structures in both images (structured noise) are removed and an image remains consisting only of differences (signal) between them. Studies have shown that dentists using the digital subtraction radiography can detect alveolar bone changes from 1% to 5% per unit volume[2], since both images are acquired under the same conditions of geometric projection, X-ray tube operational conditions and film developing. With these techniques, even subtle changes in the bone

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or dental tissue which are not perceptible for direct films comparison can be revealed[3].

Differences between two radiographic images after digital subtraction can be caused mainly by 3 factors: (a) local anatomical deformations due to progression or regression of the disease; (b) geometric changes due to projection errors; (c) intensity changes due to exposure and different parameters of film processing[4]. Anatomical differences can be identified if the two other factors are eliminated. Therefore, the geometric projection and the contrast regarding digital radiographic images to be subtracted must be standardized.

Considering the first feature above, external mechanical devices have been used to reduce possible errors of projection[5,6]. Image processing techniques allow the sequential reconstruction of images' geometry and their contrast correction before the subtraction[7]. Many researchers use manual registration of perspective projection by methods of selecting reference points marked on the image by experienced specialists. In these methods, a geometric transformation model lines up the images according to the measurements of difference and correcting distortions in geometry. There are semi-automatic methods of perspective projection registration, with manually selection of reference points only on the first image and a computational algorithm automatically determining the corresponding points in the second one[8]. Techniques of automatic registration perspective projection have been introduced into the literature[7,9].

This work rejoins the useful functionalities and tools for the evaluation of bone resorptions due to periodontal diseases by the DSR technique. Therefore, a perspective projection registration method which corrects the geometric projection and another correcting the contrast were developed. It is based on the identification of typical 'edges' in dental images to allow adjusting the geometric projection. The qualitative and quantitative subtractions help the dentist to locate the area and the type of lesion. Besides, a quantitative colored–percentage subtraction is a new approach to make the result more quantitative, since in many clinical situations the dentist needs to estimate exactly the bone gain or loss.

Methodology

In vitro radiographs were obtained from a dry jaw perforated by three different drills (with diameters of 2.9, 1.7 and 1.3 mm). Four images were obtained for each exposure time (0.17, 0.20 and 0.23 s). The first did not correspond to a perforated sample, simulating inexistence of a lesion (A); the second corresponded to the sample perforated by the drill of 1.3 mm (B); the third was perforated by the drill of 1.7 mm (C); and the fourth was perforated by a drill of 2.9 mm (D). A total of 72 pairs of images were obtained. For comparisons, they were organized into two sets, each one with 12 images, 4 for each exposure time (0.17, 0.20 and 0.23 s). In the first set, the perforation in the dry jaw was made on the vestibular and lingual cortical, and in the second set, the perforation in the jaw was only made on the vestibular cortical. These perforations were performed to check our procedure performance; therefore, they simulated bone resorption or bone gain depending on how they were compared.

The images were compared with themselves relatively to each exposure time and each set. They were all acquired from an X-707 radiographic system (Dental Yoshida MFC Co. Ltd., Tokio, Japan), with 70 kVp and 7mA. Their positioning was standardized to provide a constant ratio for the distances among the X-ray tube, the film and the object to be exposed. Supports are allowed to keep the dry jaw always in the same location, as well as the distance between the film and the object constant. All the images were digitized by a UMAX PowerLook 1120 scanner (resolutions of 600 dpi and 14 bits).

In order to perform the digital subtraction, the following procedures are achieved: (a) digitization of both radiograms to be compared, (b) alignment of the subsequent images and (c) contrast adjustment.

Discrepancies in contrast can occur in practice, mainly due to variations in a series of factors involved in the radiographic image acquisition. In order to compensate such variations, the method compares images obtained by using a same aluminum stepwedge attached to the film during the X-ray exposure. The stepwedge has 4 steps so that the areas under each one are exposed to different X-ray intensities. A comparison is performed between the average intensity in the areas corresponding to those 4 steps in each image. Thus, the dentist must select 3 circular regions, one in each step in both images, in order to calculate the average of gray level of those areas. The contrast of the subsequent image is increased or decreased according to the difference in the percentage value.

For the alignment, one image can be translated or rotated relatively to the other; therefore, the common structures to both images should be lined up in such a way that they are represented by the same pixels addresses. This procedure is performed by a manual selection of four reference points chosen by the dentist. The reference points are anatomical marks clearly visible in both images representing high contrast regions. The first ("pivot") and the three others are subsequent points. They must be marked in equal regions of high contrast in both images. The pivot point is a reference for the translation accomplishment and also a basis for the rotation calculation. All points are firstly selected in the reference image and, later, in the subsequent image.

To facilitate and improve the selecting process of these reference points by the dentist, some aid tools were incorporated, as a magnifying glass, which increases the visual information when selecting the points. In order to eliminate the salt and pepper noise caused by the coordinates recalculation by means of rotation, the median filter is applied to the rotated image, but only in pixels that did not receive any value from the rotation function. After the registration of perspective projection and the correction of resultant rotation artifacts in the subsequent image, the images can be subtracted. Three types of subtraction were implemented: qualitative, quantitative and quantitative colored-percentage. The latter is a new approach to show the information in the subtracted image, as many times the dentist needs to quantify the result.

The scheme performs the difference pixel by pixel of two images, producing a subtracted image in that each pixel represents the difference relatively to the corresponding pixels in the original images. In the qualitative subtraction pixels corresponding to the positions, where the two images are different will be white and they will be black where they are equal (Figure 1). This type of subtraction can be useful to visually determine the bone resorption due to the periodontal disease, as it can immediately display the pixels affected.

In the quantitative subtraction, pixels are added up to the mean value of the image's total intensity (for instance, in an 8-bit image the value of the subtraction will be added up to 128; for a 12-bit image, these pixels will be added up to 2048). Thus, if the two pixels are the same, the resultant image will be homogeneous, while darker pixels in the first image will be also darker in the resultant image, making any change of overlapping or the disease more easily visible (Figure 2).

In the quantitative percent-colored subtraction, the percentage of bone loss or gain is displayed by colors in the subsequent image. This is made by calculating the percentage of the corresponding pixels variation in the original images. This variation can be configured by the dentist selecting the values ranges in percentage. Thus, the subsequent image is colored, accordingly with the percentages and colors chosen by the dentist. An interval of positive or negative percentage values will show, respectively, the gain or loss registered in the subsequent image relatively to the reference image. Figure 3(a) displays the medullary bone slightly wasted by the dentists using drills, and Figure 3(b) shows an increase in the same wasted area. Figure 3(c) shows the subtraction of Figures 3(a) and 3(b). Figure 3(d) shows the quantitative percentage–colored subtraction, with the difference in a selected interval of -10 to 0%, i.e., 10% of bone loss, in yellow.

Results

The registration of perspective projection was firstly tested with different digitized images from test-objects. In the second case, the object was slightly translated and rotated relatively to the first. A pair of images was subtracted before making the subsequent image's registration of perspective projection. The result was an overlapping of both objects, resulting in an image full of noise and inadequate for use. Later, the subsequent image was lined up and subtracted from the reference image. The result was suitable: the subtraction has provided an image with

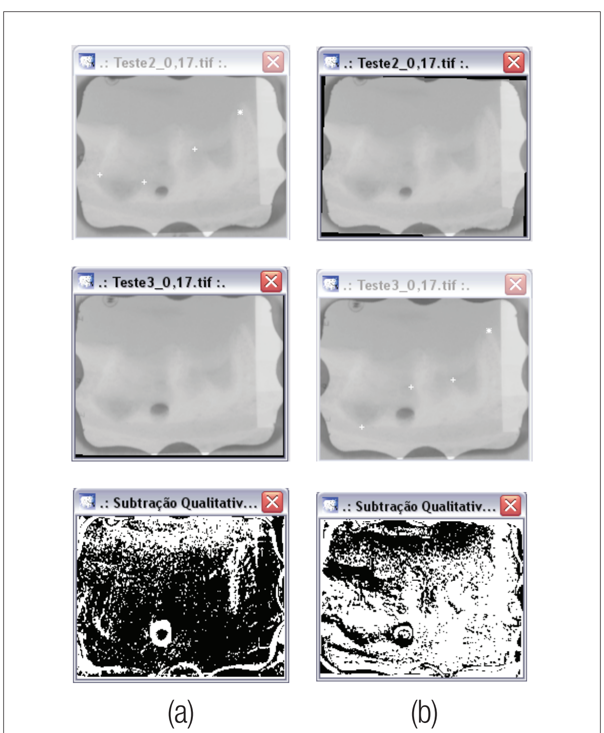

Figure 1. Qualitative subtraction: (a) with bone loss; (b) with bone gain.

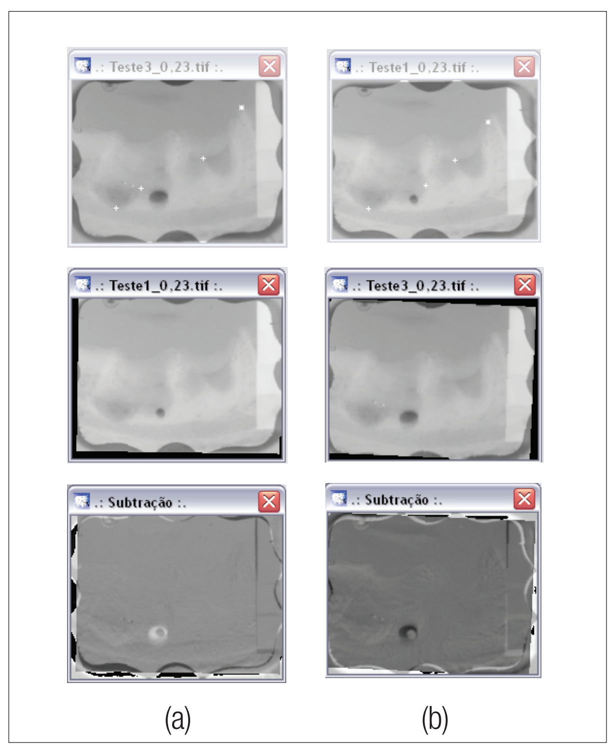

Figure 2. Quantitative subtraction: (a) with bone gain; (b) with bone loss.

homogeneous intensity, since both digitized images were equal and were not modified. After verifying the images alignment, tests were performed with radiographic dental images, as seen in Figure 4.

The drills' holes diameters in the radiograms were measured by an Olympus BHA digital projection microscope, with ±0.5 mm of tolerance. Although the diameter in the radiographic image has been increased compared to that in the object (dry jaw), the result in the subtraction is not affected, since the comparisons were made between images from the same set. Furthermore, errors due to the images digitization can be neglected since, if any variation arises during this process, both images to be subtracted are digitized by the same equipment and will present the same variations.

In order to check effectively the result from the digital subtraction scheme, a comparison was made between the desired area, resultant from a digital subtraction of two images, and the measured area. For such analysis, an algorithm was developed to count the pixels located in the area corresponding to the hole. The number of pixels in such a region in the reference image, as well as the ones of the subsequent image, was counted. Later, the subtraction was performed and the remaining pixels were counted again. The resultant pixels of the subtraction process were compared with the desired values. The error of the difference between the desired and the obtained values was calculated in percentage.

For the two sets of radiographic images (a total of 72 pairs), the average error was 7.7%. The value of this error also includes a test performed by the dentist to verify the variability in the manual method of marking points in the registration of perspective projection. This rate represents the error of all processes involved in the subtraction, i.e., the acquisition, digitization, registration of perspective projection and subtraction. The graph in Figure 5 shows the relation between the desired values (dashed lines) and the measured values in the subtraction (full lines) by the digital subtraction scheme.

The hole diameter in the radiographic image was also calculated and compared with the corresponding diameter in the digital image to found the error induced by the digitizer. The mean difference between them was 3.5%. The difference found between the diameter in the radiography and in the digital image was 3.5%, meaning that this is the error induced by the digitizer. This error can be deduced from the subtraction error found of 7.7%, lasting only 4.2% including the contrast correction and registration of perspective projection errors. For this current work, the percentage of the system inaccuracy is still very low and much more efficient than the clinical analysis, which can detect only a change of bone mineralization between 30 and 60%.

Altogether, 88 pairs of actual teeth radiographic images were subtracted. Previous Figures 3 and 4 have already illustrated results of the DSR, applied to actual patients radiographic images.

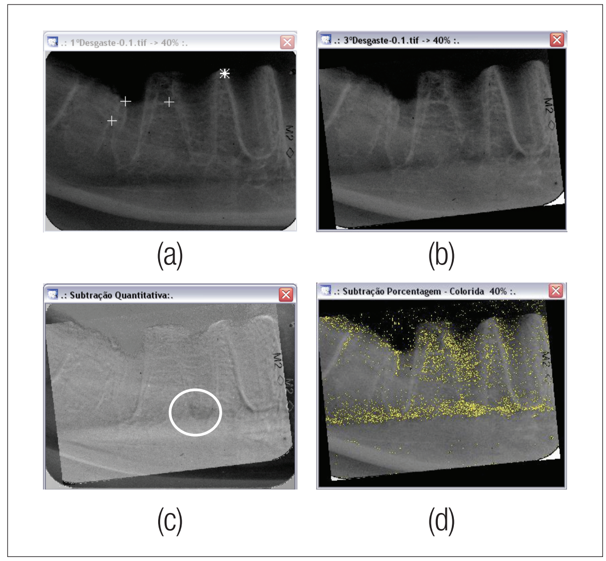

Figure 3. (a) Reference image slightly wasted; (b) subsequent image with increased waste; (c) quantitative subtraction; (d) respective percentage-colored subtraction showing 10% of bone loss in yellow.

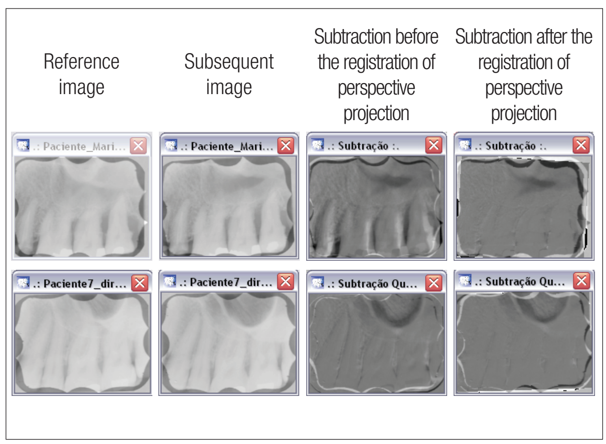

Figure 4. Tests performed for the subsequent image registration of projection perspective.

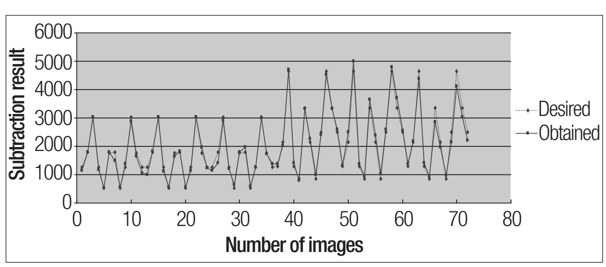

Figure 5. Relation between desired and measured results in the subtraction by the digital subtraction scheme.

Conclusions

The subtraction scheme proposed here is dependent on the whole image acquisition process (imaging, film development and digitization). The imaging process must be totally reproducible later. Thus, the same X-ray system and operational conditions should be used. A positioning standardization method providing a constant relation regarding the distances between the X-rays tube, film and object to be exposed is also recommended to be used in order to assure that there are not great distortions relatively to the geometric projection. Images digitization should keep the reproducibility of parameters (same spatial and contrast resolutions and noise level). It assures that both images to be subtracted will be obtained and digitized with the same characteristics so that such parameters will not affect the subtraction final result.

The DSR is primarily an operation to improve the visual information, and the role of the dentist in detecting the signal is still important. Moreover, the quantitative percentage–colored subtraction is a new approach of the subtraction result to make it more quantitative, since in many clinical situations the dentist needs to evaluate the amount of bone gain or loss. Thus, the dentist will be able to visualize by the colored areas in these percentages. This is an improvement compared to other works in literature, since it is not pseudo-color, but another way of registering quantitatively the bone gain or loss.

In many clinical situations requiring digital subtraction, there is no specific system, and dentists are likely to use generic image processing programs. Therefore, this procedure can work as an aid diagnosis tool and it will be useful to the dentists for the evaluation of bone resorption due to periodontal disease, contributing for an early diagnosis to establish the best treatment and to increase its possibilities of success. This program is currently available for free download at http://lapimo.sel.eesc.usp.br/lapimo/LapimOdonto.htm.

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