A posteriori registration and subtraction of panoramic compared with intraoral radiography

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Objectives. To demonstrate the feasibility of panoramic image subtraction for implant assessment.
Study design. Three titanium implants were inserted into a fresh pig mandible. One intraoral and 2 panoramic images were obtained at baseline and after each of 6 incremental (0.3, 0.6, 1.0, 1.5, 2.0, 2.5 mm) removals of bone. For each incremental removal of bone, the mandible was removed from and replaced in the holding device. Images representing incremental bone removals were registered by computer with the baseline images and subtracted. Assessment of the subtraction images was based on visual inspection and analysis of structured noise.
Results. Incremental bone removals were more visible in intraoral than in panoramic subtraction images; however, computer-based registration of panoramic images reduced the structured noise and enhanced the visibility of incremental removals.
Conclusion. The feasibility of panoramic image subtraction for implant assessment was demonstrated. **(Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;108:e39-e45)**

Subtraction of dental images is used to make the image contrast reflect the subject contrast and to emphasize the differences between 2 images.[1] To standardize the source-object-receptor alignment for intraoral images, bite-blocks with sensor holders are used.[2] A posteriori computer registration of images is also used.[3,4] Digital subtraction of intraoral images has been used for caries diagnosis,[5] periodontics, implantology,[6-9] and assessments of changes in condylar positions.[10] For implant treatment planning and follow-up control (particularly for total reconstructions), panoramic radiography is commonly used rather than multiple intraoral radiographs.[11] With panoramic radiography, it is difficult to control the placement of the subject relative to the x-ray source, with small differences in placement having large effects on resulting images. For this reason, panoramic radiography has not been commonly used for performing image subtraction. Panoramic digital subtraction was, however, found significantly better than panoramic radiography for the detection of bone chips that were placed on the mandibular condyle.[12] A limitation of this study was that the mandibular condyle was not removed from the holding device when the bone chips were changed. Our objectives were to answer the following questions:

1. Is computer-based a posteriori registration and digital subtraction applicable to panoramic imaging?
2. Is incremental bone removal around implants observable in panoramic subtraction images?
3. Is the visibility of incremental bone removal around implants equivalent in intraoral and panoramic subtraction images?

MATERIALS AND METHODS

In vitro model

After a full-thickness flap was raised, 3 9.5-mm-long titanium SIC Ace implants (SIC-Invent, Basel, Switzerland), 2 with a diameter of 4.0 mm and 1 with a diameter of 5.0 mm, were inserted (parallel to each other) into the inferior border of a fresh pig's mandible (Fig. 1). The implant shoulders were epicrestal, with the implant bodies surrounded by buccal and lingual bone plates that were each at least 2 mm in thickness. Abutments were screwed onto the implants. After repositioning the flap, the mandible with the implants was radiographed.

Serial removal of bone

After the baseline images were obtained, crestal bone around the 3 implants was serially removed with a scalpel. The total amounts of bone removed were mea-

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Fig. 1. Fresh pig mandible with 3 implants is positioned in the panoramic imaging unit.

sured with a periodontal probe and were 0.3 mm, 0.6 mm, 1.0 mm, 1.5 mm, 2.0 mm, and 2.5 mm (Fig. 2).

Process of repositioning

For the intraoral images, the mandible was placed in silicone (Optosil Comfort Putty; Heraeus-Kulzer, Wehrheim, Germany), into which a CCD chip sensor was placed parallel to the implants. This setup for intraoral imaging was used in every test run without changing the position of the CCD chip sensor. For the panoramic images, a special metal holder with 3 silicone pads was used. The pig mandible was placed in and removed from this holder (Fig.1). The silicon pads were designed to prevent the mandible from falling out of the imaging device and to allow ±15° transversal and ±5° sagittal freedom in positioning of the mandible. For each panoramic image, the mandible was removed from the holder and the holder was removed from the panoramic machine. A ruler was used to position the mandible at approximately the same vertical position in the panoramic machine for all exposures. Two dentists alternated in positioning the mandible in the machine.

Image acquisition

For each test run, two panoramic images and one intra-oral image were obtained. Altogether, 21 images were obtained: (base + 6 incremental removals) × (1 panoramic + 2 intraoral images). The digital x-ray equipment for intraoral imaging was a CCD chip sensor with a pixel size of 38 μm (ser. no. 174168; Planmeca Dix, Helsinki, Finland), used with an x-ray tube for intraoral radiography (Prostyle Intra; Planmeca, Helsinki, Finland). For the panoramic images, the CCD chip sensor had a pixel size of 132 μm (Promax RPX 232574; Planmeca). The adjustments for panoramic and intraoral imaging were 58 kV, 8 mA, 16 s and 63 kV, 8 mA, 0.20 s, respectively.

Image preprocessing

Each image was evaluated with Dimaxis Software 3.1 (Planmeca) and stored in lossless tagged image file format (TIFF). The images were transfered to a Linux-operated workstation. Image preprocessing was performed using ImageMagick 6.3.6 (ImageMagick Studio, Landenberg, PA), a free software suite that can be used to create, edit, and compose bitmap images.

The panoramic images were 2,424 × 1,032 pixels. From each of these, we extracted a region of interest (ROI) of 240 × 220 pixels (Fig. 3). The intraoral images were 924 × 528 pixels. We reduced the size of these by a factor of 2 and cropped them to 458 × 253 pixels.

Image registration

We applied automatic a posteriori registration with the National Library of Medicine's Insight Segmentation and Registration Toolkit (ITK; Kitware, Clifton Park, NY). ITK provides a library of C++ modules, which can be variously combined to compile distinct image processing applications. The ITK registration framework consists of 4 components (transform, interpolator, metric, and optimizer; Fig. 4[13]). Following are brief descriptions of these.

Transform. The most important design decision for computer-based registration is the choice of the appropriate transform. With fixed-source object geometry, plain x-ray imaging results in rigid (rotation and translation) and perspective transforms for parallel and cone beam, respectively.[14] Image formation in panoramic imaging is, however, far more complex, and a closed-form deconvolution model is not known. Because the data results from line-by-line exposure, we chose the affine transform to model rotation, translation, scaling, and shear strain, and to prevent local elastic deformation, because such deformation might obscure the effect to be measured.[14]

Interpolator. In general, geometric transforms, except, integer shifts in the *x* or *y* direction, can not be performed on a discrete grid. An interpolator virtually computes the continuous image and resamples it on an appropriate transformed grid. Well known simple and

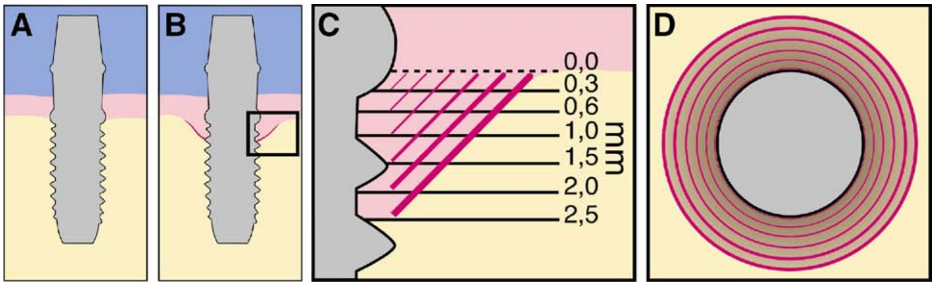

Fig. 2. Simulation of bone defects. **A,** Implant without no bone removal (baseline); **B,** bone removal; **C,** stepwise removals of bone (window enlargement as marked in B. **D,** Top view of implant showing the circular nature of bone removals.

Fig. 3. Image preprocessing: original panoramic with 2424 × 1032 pixels (**top**), resulting bitmap after preprocessing with 240 × 220 pixels (**bottom left**), intraoral x-ray after preprocessing with 458 × 253 pixels (**bottom right**).

computationally efficient interpolation schemes include nearest neighbor, linear, and cubic convolution.[15] We chose the linear interpolation scheme, because it produces fewer artifacts than the nearest-neighbor approach, and it is computationally efficient.

Metric. Mutual information is a measure derived from information theory that quantifies the dependencies of 2 random variables.[16] It is known to have superior properties for determining image similarity, particularly for registration of images acquired with different modalities.[17]

Optimizer. A brute-force registration can be implemented as follows: 1) For all combinations of transform parameters, compute the transformed image using linear interpolation; 2) determine the similarity of the reference and transformed follow-up images by using mutual-information techniques; and 3) select the transform parameters that result in the best overall similar-

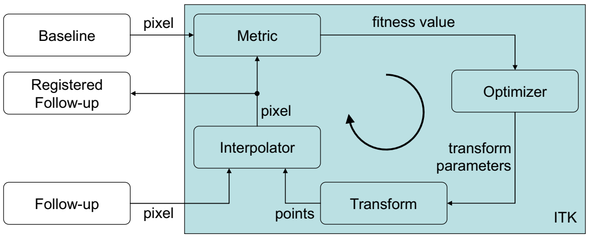

Fig. 4. The 4 basic components of the ITK registration framework (transform, metric, interpolator, and optimizer). The 2 input images are the baseline and follow-up; the output is the resulting registered follow-up image.[13] The loop terminates when the criteria for an acceptable fit are satisfied.

ity. To substantially reduce the computing time, an optimizer is used to locate the best similarity within the transform-parameter space without calculation of all possible combinations. For our optimizer, we applied the regular step-gradient descent method within a 3-level multiresolution strategy. We obtained an additional speedup by performing a preregistration step that is based on the rigid transform, linear interpolation, mean square image-to-image metric, and a regular step-gradient descent optimizer.

Qualitative and quantitative evaluation

To qualitatively assess subtraction images, a gray value of 128 was added to the images, which were clipped to 8 bits. As a result, areas without change appeared gray, and increasing or decreasing x-ray absorption was coded as a brighter or darker area. Size and grayscale of such areas were also qualitatively assessed with a subtraction-image histogram, with the frequency plotted on a logarithmic scale and with the symmetry of structured noise used to indicate the parts of the signal that resulted from bone removal.

Quantitative evaluation was based on pixelwise grayscale analysis of the subtraction images. We used the standard deviation of the histogram of the grayscale values in the subtraction images to evaluate noise.[18] In previous work, we demonstrated that this measure can be computationally simplified, and similar performance is obtained, by considering only the standard deviation or variance of the difference image.[19] To ensure that our quantitative evaluation was insensitive to the border effects resulting from partial image overlap, we computed the variance as a quantitative measure m of structured noise from centered rectangular regions in the subtraction images.

Experiments

To investigate whether computer-based a posteriori registration and digital subtraction is applicable to panoramic images, we compared the 7 pairs of panoramic images that were obtained before and after readjustment. Qualitative and quantitative analyses were used. The hypothesis that "subtraction is applicable to panoramic radiography" was supported if the resulting subtraction images had decreased structured noise. For statistical analysis of small sample sizes ($n = 7$), we used the paired Wilcoxon test, with α set at .05.

Whether or not serial removals of bone were observable in a posteriori–registered panoramic images was analyzed qualitatively. Images representing the 6 serial bone removals were subtracted from the baseline image after a posteriori registration. Furthermore, we qualitatively compared the degree to which serial bone removals were detectable in both panoramic and intraoral subtraction images.

RESULTS

A posteriori registration of panoramic images

Figure 5 shows the subtraction images before and after the 2-stage affine registration. The lack of a priori registration is indicated by the high level of structured noise (Fig. 5, *top*). In serial images, this noise limits the image information that corresponds to unchanging morphologic structures over the temporal period of data acquisition.[2] Our goal in applying a posteriori registration was to reduce this structured noise. The procedure decreased the noise levels in the subtraction images (Fig. 5, *bottom*). The differences in the quantitative noise measures m were statistically significant (Table I; $P < .05$).

Digital subtraction imaging based on panoramic images

Serial removals of bone are visible in a-posteriori-registered subtraction images (Fig. 6, *top*). The minimal defect size that was detectable was 1.0 mm. This suggests that meaningful interpretation of subtraction imaging based on a posteriori–registered panoramic images is possible.

Intraoral versus panoramic image subtraction

Figure 6 (*bottom*) are the corresponding intraoral subtraction images. The minimal defect size that was detectable was 0.6 mm. Figure 7 is a display of the ROIs for the largest defect size (2.5 mm) and the corresponding logarithmic plots of the histogram. The symmetric part is lower and wider for panoramic subtraction. This suggests a higher level of structured noise in panoramic-based subtraction. The asymmetric part of the histogram corresponds to the bone removals. It is larger for intraoral subtraction. The amplitudes of the darkest pixels for intraoral and panoramic subtraction were 97 and 60. This suggests that the bone re-

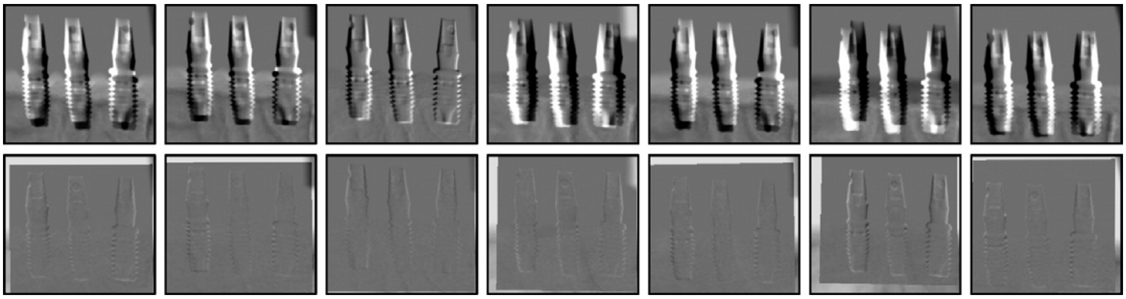

Fig. 5. Subtraction with identical settings: In each of the 7 test runs, 2 radiologists positioned the pig mandible and panoramic system to acquire the images. Subtractions based on ROIs of panoramic images before and after a posteriori registration are shown in the **top** and in the **bottom** rows, respectively.

Table I. Structured noise as measured by the variance of the difference images, *m*

Defect size (mm)	*0.0*	*0.3*	*0.6*	*1.0*	*1.5*	*2.0*	*2.5*	*Mean*	*SD*
Unregistered	2,575	2,201	1,210	4,516	3,017	4,203	3,462	3,026	1,153
A posteriori registered	19.2	10.8	18.1	16.7	11.0	52.8	13.4	20.3	14.7

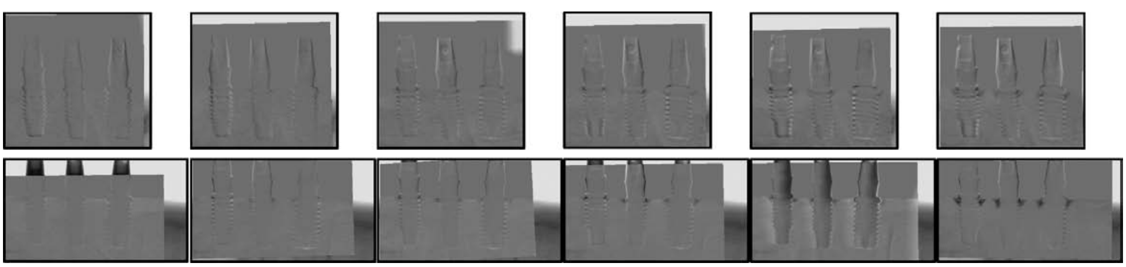

Fig. 6. Subtraction to demonstrate bone removals. A posteriori registration is performed based on panoramic (**top**) and intraoral (**bottom**) images. The bone removals increased from 0.3 mm (**left**) to 2.5 mm (**right**). The high amount of structured noise that is visible in the subtraction based on intraoral images for defect size 2.0 mm (*bottom, secondmost right*) is caused by a readout error of the digital sensor and is not of relevance for this study.

movals were more detectable with intraoral subtraction images than with panoramic subtraction images.

DISCUSSION

In a recent review, the advantages of direct digital imaging in dental radiology was stressed.[20] Digital modalities allow the dentist to perform mathematic operations for image enhancement and also take advantage of advanced techniques, such as geometric registration, digital subtraction, and computer-aided recognition of image features. Ours is the first published study of a posteriori registration of serial panoramic images for which the radiographed object was moved between exposures. In panoramic radiography, the image creation process is complex, and misalignments result in different images. Mutual-information techniques have, however, been used successfully not only for registration of 2-dimensional (2D) images of a single patient, but also for multimodal 2D-to-3D and 3D-to-3D registration problems in intra- and interindividual clinical applications.[21] Motivated by these applications, we used the mutual-information measure to compute serial panoramic registration without attempting the deconvolution of the panoramic image formation process.

Under highly controlled experimental conditions, the potential of using digital subtraction techniques with panoramic images was demonstrated.[12] With more relaxed experimental conditions, we demonstrated that panoramic subtraction images can be used to detect serial removals of bone.

There are several limitations with our study. Our methods can probably not be used in image areas where a structure such as the spine is superimposed. In such a

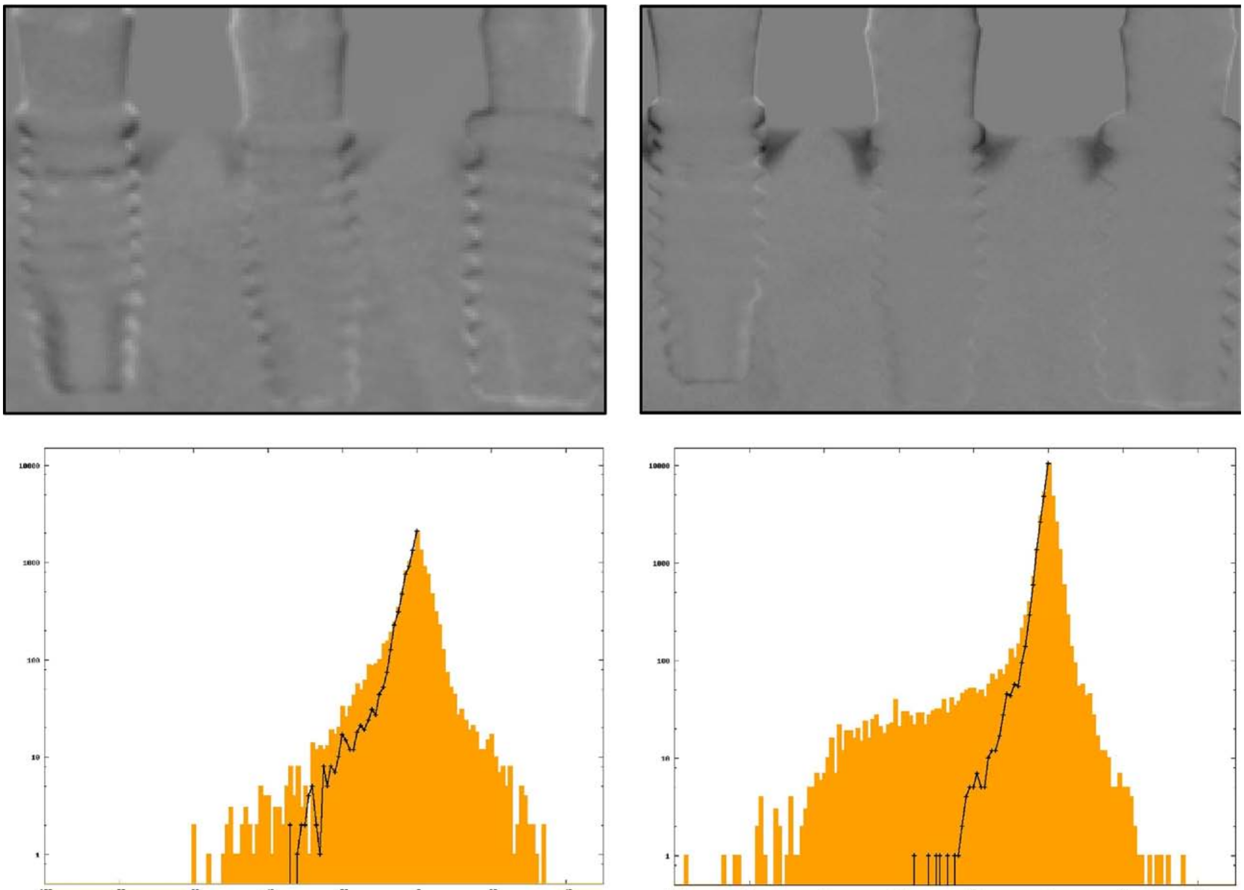

Fig. 7. Panoramic versus intraoral subtraction. ROIs for 2.5-mm defect sizes (**top**) and logarithmic histograms (**bottom**) for a posteriori registered panoramic (**left**) and intraoral subtraction images (**right**). The distribution resulting from structured noise is plotted in black. The signal above this line indicates the removed bone and is larger for intraoral subtraction (*right*).

region, subtraction of intraoral images would be preferable. This restriction also applied to the superimposition of structures and ghost images. Our study is also based on only 1 jaw from a pig. This experimental set up may not be representative of using the methods with humans. Compared with an earlier study that used dry skulls that were in fixed positions, our pig mandible had soft tissue, and we repositioned it after each incremental bone removal.[12]

The ROI extracted from the panoramic image extended from the cuspid to the second molar and was approximately 25 × 50 mm. This size for the ROI is sufficiently small that panoramic image distortions are minimal. We plan to perform further studies to determine the extent of geometric distortions in panoramic images, the optimal ROI size, and the minimal size of detectable lesions.[22] These studies will include more extensive evaluations by observers and a visual analog scale to assess the detectability of defects.

We demonstrated in this study that alveolar bone removal was more detectable on intraoral subtraction images than on panoramic subtraction images. Because the image formation geometry of panoramic radiography is complicated and difficult to deconvolve, our strategy was to simplify the model and apply affine registration to our extracted ROIs. We think that we will be able to achieve further improvements by improved modeling of the rotational panoramic image formation process.[23]

CONCLUSION

It is a common assumption that panoramic image subtraction is impossible because of the large distortions that result from geometry misplacements among the serial images, but we have demonstrated the feasibility of this approach by using computer-based automatic a posteriori image registration techniques. To the best of our knowledge, techniques for subtraction based on nonstandardized panoramic images have not been previously published in the literature. In the future, this technology might contribute to improved implant therapy planning and evaluation.

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