Clinical Report

Digital Subtraction Technique for Evaluation of Peri-Implant Bone Change in Digital Dental Imaging

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Abstract

The purpose of this study was to investigate digital subtraction technique in digital dental imaging for implant performance, used to quantitatively evaluate bone change around dental implants. For longitudinal assessment of peri-implant bone change, we applied subtraction technique to digital peri-apical radiographs using a digital dental imaging system in two cases at the upper canine and premolar regions. In both cases, we found two peaks of bone change at the crestal region; we also quantitatively demonstrated a marked change over the first one-month period and approximately three-month period spanning the fourth month to the end of the sixth month following implantation. Digital peri-apical radiography accommodating the digital subtraction program should be re-acknowledged as a reliable modality for assessing amount of bone change at local implantation sites.

Key words: Digital subtraction—Digital dental imaging—Bone change—Dental implant

Introduction

Radiographs are an important tool for obtaining consistency of evaluation during dental implant therapy. They are commonly used at each of the four phases of implant therapy, which include each stage of pre-surgical assessment, implantation, tissue-interface formation and carrying out actual dental implant. Radiography provides infor-

mation on the location of any anatomical structure of interest in such work, which will include the inferior alveolar nerve in the mandible, the floor of the maxillary sinus in the maxilla¹⁵⁾, and the amount of available bone. In other words, the purpose of radiographic examination is to provide precise measurement of distance so that the dentist may a) decide the length, width and course of implantation, b) qualitatively evaluate amount

of bone at potential implant site during pre-surgical assessment, and c) longitudinally evaluate peri-implant bone change immediately after implantation to restore masticatory function.

Subtraction radiography for measurement of bone change was introduced in the field of periodontal research in the 1980s, and is one of the most versatile methods available^(6,9,12,25). Jeffcoat *et al.*⁽¹³⁾ used this method together with gray scale difference to measure area of bone change in implant performance analysis. They used a reference wedge calibrated at different thicknesses, which was incorporated into the peri-apical radiograph. The image of the wedge obtained from subtraction was used to determine the thickness of the wedge that corresponded to the same gray level change as the bone loss area. However, this method had no practical use in clinical trials. Recently, a subtraction soft-ware program employing a computer matrix transformation algorithm has been developed, offering an effective tool for use with this method.

This purpose of this paper is to report quantitative evaluation of bone change around implants from digital dental imaging, and to consequently advocate the subtraction technique in longitudinal assessment of amount of bone change for implant performance.

Materials and Methods

We used the Digora digital dental imaging system (Soredex/Finndex, Helsinki, Finland), which is based on a storage phosphor plate with a laser-beam read-out device connected to a computer, to longitudinally evaluate bone change. A trial version of the subtraction software program, "before-and-after" (Yoshida, Co, Tokyo, Japan), which supports direct digital dental imaging, was used to longitudinally evaluate bone changes after implantation. This soft-ware program employs a computer matrix transformation algorithm, which together with standardized geometric relationships minimizes image distortion caused by misangulation error of the detector and

x-ray beam. Its utility was demonstrated in two cases of implant fixtures at the right maxillary canine and premolar region. The implant fixtures were ultrathin-Hydroxyapatite (HA)-coated implants made by the thermal decomposition method (Platon Implant Japan, Tokyo), which are non-submerged (1-stage) implants for use in proximity to edentulous sites. Implantation was carried out under local anesthesia. Incision of the alveolar crest was carried out in the standard fashion, and sufficient operational view was secured. After a proper implant base was formed with a drill to the required thickness and length, the implant fixture was implanted. Finally, the gingiva was trimmed and sutured, and the implant operation completed. After about four months, an abutment was attached in the upper jaw.

Digital dental images were taken prior to surgery by conventional paralleling technique, using an occlusal surface impression with a hard body impression material attached to a bite-block. The bite-blocks were saved and re-used for postoperative dental examination. With the aim of ascertaining morphological variations in the bone at the unilateral alveolar process margin around the implant fixture, digital images were taken at baseline in the aftermath of implantation, and at 1, 3, 4, 5, 6, 9 and 12 months for the canine region, and at baseline in the aftermath of implantation, and at 1, 2, 3, 4, 6 and 9 months for the premolar region. All digital images were obtained with the a dental x-ray generator with a $0.8 \times 0.8 \text{ mm}^2$ focal spot, a total filtration of 2.0 mmAl, operated at 70 kVp and 7 mA. The digital images obtained at each stage were also rigorously standardized *a priori*. The images, with the storage phosphor plate kept parallel and the x-ray beam perpendicular to the implant, were taken using an individually fabricated bite-block with a film-holder. (Fig. 1). With regard to exact placement of the holder, given that impressions of the teeth were available, it was assumed to be within a few degrees in all possible combinations of all planes, since there was a mechanical connection to the open-end cone of the dental x-ray

Fig. 1

machine. Additionally, the subtraction software program used included features for correcting contrast differences and geometric misalignments in the two images to be subtracted. Consequently, the image data had very few reversible projection errors.

The quantitative measuring method used for bone morphological variations is shown in Fig. 2. First, two images to be subtracted were selected and opened from the image files, and then the red frame for correcting the position of both images was indicated on a monitor. To position the image, analysis of the characteristics of each image inside the red frame was performed automatically, taking into account amount of movement and rotation, and then the base-line image was superimposed on and subtracted from the corrected subsequent image by subtraction program. Alternation area was displayed in red when the difference of pixel values on a subtraction image was more than 20. The threshold for segmentation was decided taking into consideration detection sensitivity. Consequently, bone qualitative alternation area was displayed in red. The alternative area, the number of pixels displayed in red, was then calculated by subtracting the number of pixels of an unchanged area from

the total number of pixels of the region of interest (ROI). Each ROI at the alveolar process margin around the implant fixture was respectively set as rectangles of the same size by reference to the grid scale. The number of pixels was calculated using Photoshop 5.0 J (Adobe Systems Japan, Tokyo, Japan).

Results

Figures 3A and 3B respectively show the original and subtraction images with rectangle ROIs obtained at each stage in the canine region. The results for total pixel number of alternative areas obtained from the subtraction images at each stage are shown in Fig. 4. Correspondingly, Figs. 5A and 5B, and 6 show the results for the premolar region. In both the canine and premolar regions, morphological change at the alveolar process margin around the implant fixture was remarkable from the aftermath of implantation to at three months after (Figs. 4 and 6). Alveolar bone at the crestal region in the canine and premolar regions showed marked change at one-month period after implantation, with this alternation decreasing until about three or four months after. Additionally, another peak of bone change was observed at from about three to four-months to six-months after implantation.

Discussion

Many authors maintain that CT images, which are digital images, are the most accurate technique for implantation site diagnosis for pre-surgical assessment^{8,14,16,19,22}. Their advocacy commonly results from the minimal geometric distortion and availability of not only two-dimensional panoramic and cross-sectional formats, but also three-dimensional images that this technology offers. However, for longitudinal assessment in routine follow-up clinical research regarding bone change after implantation, which is what we addressed in this study, CT may not be practical because

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

it requires a higher exposure dose than not only digital dental systems with peri-apical radiography, but also other modalities, and streaking caused by metal artifacts used for abutment connection after implantation. Meanwhile, peri-apical radiographs are used to evaluate limited areas or individual implant sites. When intra-oral films are well-angulated, applying the standardization of projection geometry previously described by Duckworth *et al.*⁴⁾, peri-apical radiographs have minimal distortion. Additionally, the subtraction software program used in this study includes

features to correct for contrast differences and geometric misalignments in the two images to be subtracted. Digital image data obtained by peri-apical radiography may have very few reversible projection errors, and is possibly appropriate for application of digital subtraction technique. Furthermore, peri-apical radiography taken with a direct digital dental imaging system accommodating a subtraction program may be well-suited for longitudinal assessment of bone change after implantation because of the objective description, quantitative evaluation and low

exposure dose^{2,10)}, even though the resolution of the image is less than that available with conventional film-based image²⁶⁾. Incidentally, the spatial resolution of the Digora digital dental imaging system used in this study is about 80 μm , and is extremely low, comparing with that of medical CT; about 500 μm , or cone-beam CT; about 200 μm , although there are some differences among the various kinds of CT system.

The etiologies of early bone change occur during healing, and surgical trauma^{3,5)}, occlusal overload^{11,20)}, peri-implantitis^{23,24)}, the presence of microgaps for submerged (2-stage) implants^{1,21)} and crest modules of the implant body^{7,18)} have all been proposed within the first year of implant function. Although only two cases using the subtraction method were presented for illustration, the regions with longitudinal bone change could be evaluated quantitatively. Vertical bone resorption in close proximity to the crestal module of the implant fixture during one-month period after implantation, in particular, was a common finding in both cases. This was caused by heat generated at the time of drilling and excessive pressure at the crestal region during surgical treatment. Early bone loss as a surgical trauma may result in an environment that is favorable for anaerobic bacterial growth, and induce peri-implantitis. Peri-implantitis possibly contributes to more bone destruction in the following months or years. However, the amount of bone change at the crestal region in these cases was dramatically reduced to three or four months after. Peri-implantitis may not have been the main causative factor of early implant bone change at the crestal region. Additionally, the possibility of occlusal overload, which often results in marginal bone loss, was also low due to no connection of abutment. Meanwhile, another peak of bone change amount occurred during about three to four months to six months after implantation. This stage corresponded to the time of connecting an abutment in these cases. This suggests that loading with the abutment resulted in crestal bone change. The crest module of an implant

fixture serves as the region which receives the crestal compressive stress to the implant after loading. Implant fixtures with a straight crest module transmit shear force to crestal bone, whereas those with an angled collars, such as that used in this study, transmit some compressive force to crestal bone¹⁷⁾. Crestal module design may also induce a slight crestal bone change. Crestal bone loss caused by microgap is usually observed in submerged implants, typified by the Brånemark implant. In this study, non-submerged (1-stage) implants were used. In non-submerged implants, the implant itself extends above the alveolar crest level; hence, a microgap probably does not exist at the level of the bone. Consequently, it is quite unlikely to induce the crestal bone change.

The trial version of the digital subtraction software program used in this study has been improved to allow quantitative evaluation of alveolar bone change, meaning amount of bone change, not alteration of bone density or quality. Unfortunately, this program is not available for assessment of differences between bone resorption and bone addition. Hence, it does not matter which image is used to make a base-line image when two images are superimposed and subtracted. However, the improvement of this program is being continued with the cooperation of our department, and it will be possible to evaluate these differences in the near future.

In conclusion, digital subtraction technique accommodating a digital dental imaging system should be acknowledged as a reliable method for quantitatively and longitudinal assessing amount of bone change at local implantation sites.

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Legends of Figures

- Fig. 1 Device positioned with bite-registration impression material
* Positioning ring is aligned with X-ray cone.
- Fig. 2 Example of subtraction radiograph and way to quantitatively evaluate bone morphological variations at unilateral alveolar process margin around implant fixture
* Image of aftermath of implantation was superimposed on and subtracted from image at one month after implantation by subtraction program, and then subtraction image was segmented with red. Bone alteration area, which is displayed in red in "region of interest (ROI)", was calculated as number of pixels with histogram.
- Fig. 3 A) Original images obtained at each stage at canine region
B) Subtracted images obtained at each stage at canine region
* Additional note under each image such as 0-1M signifies image at aftermath of implantation and at one month after implantation was superimposed and subtracted.
* Rectangles on each subtracted image are "region of interest (ROI)" to quantitatively measure bone change.
- Fig. 4 Graph showing longitudinal bone change at each stage at canine region
- Fig. 5 A) Original images obtained at each stage at premolar region
B) Subtracted images obtained at each stage at premolar region
* Additional note under each image such as 0-1M means that image at aftermath of implantation and at one month after implantation was superimposed and subtracted.
* Rectangles on each subtracted image are "region of interest (ROI)" to quantitatively measure bone change.
- Fig. 6 Graph showing longitudinal bone change at each stage at premolar region