Osseointegration Assessment of Dental Implants Using a Synchrotron Radiation Imaging Technique: A Preliminary Study

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Purpose: *This study tests the possibility of using synchrotron radiation (SR) x-ray micro-imaging as a new method to evaluate osseointegration.* ***Materials and Methods:*** *A simple imaging setup with primarily unmonochromatic SR was used to study the interface of a dental implant in contact with bone. The samples were prepared by sectioning the undecalcified specimen of a titanium screw implanted in the tibia of a New Zealand white rabbit. Radiographs of the interface between surrounding tissues and dental titanium implant were imaged using the SR imaging system at PLS (Pohang Light Source) 5C1 beamline, a micro-computed tomography (μCT) system (SkyScan-1072), and a conventional dental x-ray system (Siemens Heliodent MD).* ***Results:*** *The image quality of the osseointegrated titanium implant was compared among the 3 imaging systems. The SR imaging technique showed greater details than other radiographic modalities for evaluation of the healing stage of bone-implant contact.* ***Discussion:*** *The evaluation was especially focused on the image quality of the osseous contact at the bone-to-implant interfaces.* ***Conclusions:*** *This SR imaging technique provides finer details and can be expected to make an impact in the clinical study of osseointegration.* (INT J ORAL MAXILLOFAC IMPLANTS 2003;18:121–126)

Key words: *dental implant, dental radiography, osseointegration, synchrotron radiation*

Since the early 1960s, there have been many advances in the understanding of the osseointegration concept and its application to implant dentistry. The term "osseointegration" was initially defined as the direct contact between a dental implant and surrounding bone without an intervening fibrous tissue layer at the interface.[1,2] After implantation, bony ingrowth anchors the surrounding alveolar bone to the dental implant surface. Analysis of the direct bone-implant interface can provide an indication of successful endosseous dental implantation. The degree of bone-to-implant contact has been evaluated with microradiography,[3] histology and morphology via optical microscopy or scanning electron microscope (SEM),[4–8] and pullout tests, the resonance frequency technique,[9–12] or Periotest[13,14] to assess mechanical stability.

This study proposes the use of the synchrotron radiation (SR) imaging technique, which has sufficiently high spatial resolution to evaluate the contact of bone-to-implant. Radiographs produced by a modern SR source have recently been introduced as an alternative x-ray source whose high photon flux, collimation, and coherence are capable of high-resolution images down to the micrometer scale.[15–18]

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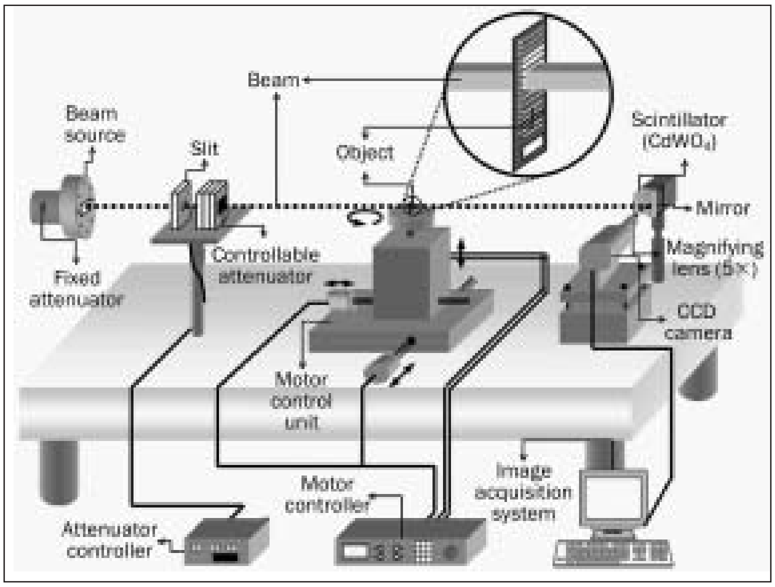


Fig 1 Schematic diagram of the PLS 5C1 unmonochromatized synchrotron radiation imaging system.

In this preliminary study, to appreciate the higher image quality of the SR micro-imaging techniques, radiographs of a lateral incisor and a test dental titanium implant specimen produced by conventional dental radiography and by a micro-computed tomography (µCT) system were compared with those obtained by the SR imaging system. The possibilities of using SR microradiography to assess bone-to-implant contact were evaluated based on this comparison.

MATERIALS AND METHODS

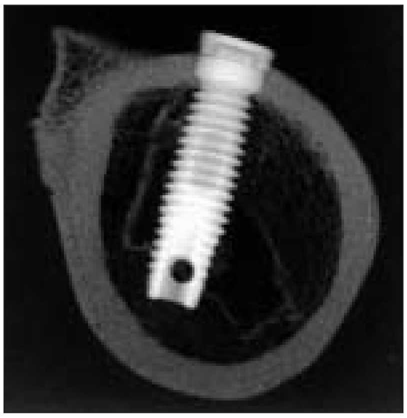
The SR imaging experiment was performed at the 5C1 beamline (constructed for surface x-ray scattering and medical applications) of Pohang Light Source (PLS), which is a SR facility installed at Pohang Accelerator Laboratory in Pohang, Korea. The PLS is a third-generation SR source consisting of a 2.0-GeV electron linear accelerator and an electron storage ring (2.0 to 2.5 GeV) supporting an average beam current of 400 mA at 2.0 GeV and 250 mA at 2.5 GeV. The SR passing through the test object then interacts with the scintillator screen, a thin plate of cleaved single-crystal cadmium tungstate ($CdWO_4$), before being converted to a visible-light image. Visible-light images can then be magnified by microscope optics, captured by a charge-coupled distributor (CCD) array detector (Photometries Cool SNAP: 12 depth-bit, 1,392 × 1,040 pixels with 4.65×4.65 µm^2, Trenton, NJ), and transferred to a computer for data acquisition and analysis (Fig 1).

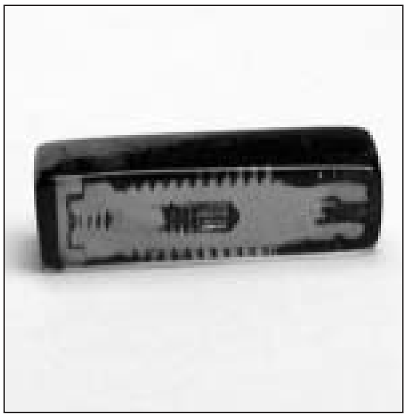
In this investigation, a series of silicon wafer filters were placed into the beam upstream of the object position and used to modify the photon energy spectra and output intensity. Depending on the total thickness of silicon wafers, an average of 10^{11} to 10^{12} photons per second were delivered to the sample with energy of 6 to 16 keV. The typical incident beam size was 10×10 mm^2, defined by an aperture placed upstream of the silicon filter. The sample-to-scintillator distances were varied from 35 to 470 mm to obtain the best image condition, depending on the test objects. During measurement, test objects were scanned with respect to the x-ray beam by a multi-axis mechanical stage, and the complete sample image was obtained by patching together smaller individual images.

In this preliminary study, a female adult New Zealand white rabbit, 3 kg in weight, was used. The Committee for the Care and Use of Laboratory Animals at Yonsei University College of Medicine reviewed all experimental procedures on the basis of "Guide for Animal Experiments." A commercially pure titanium (cpTi) screw-type implant, 10 mm in length and 3.8 mm in diameter (Dong Myeong, Seoul, Korea), was placed in the tibia of the rabbit. For general anesthesia, 50 mg/mL ketamine hydrochloride (Ketalar, Yuhan, Seoul, Korea) 2 mL/kg was injected intramuscularly, and 2% lidocaine hydrochloride (Yuhan) with epinephrine (1:100,000) was administered under aseptic conditions at the surgical site. A skin incision was made on the right side of the rabbit tibia and a flap was created to expose the tibia. The drilling and implant placement were done under copious saline irrigation. Tapping was limited to the cortical bone. After implant placement, the periosteum and fascia were sutured with resorbable suture material (polyglactin

Fig 2a *(Left)* Conventional dental radiograph of a screw-type titanium implant placed into the tibia of white rabbit.

Fig 2b *(Right)* Photograph of the prepared titanium implant specimen used in the osseointegration analysis.





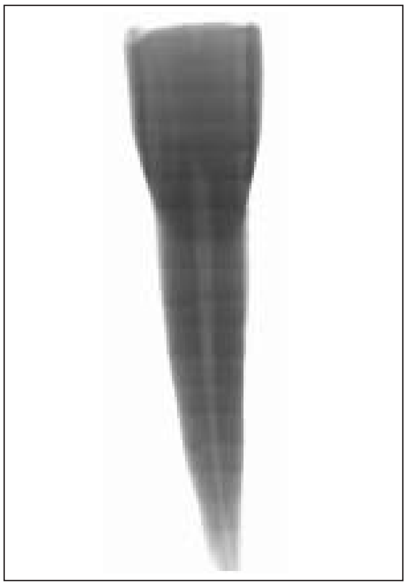


Fig 3a Radiographic image of a lateral incisor obtained with the SR imaging system.

Fig 3b Radiographic image of a lateral incisor obtained with commercial micro-computed tomography (μCT).

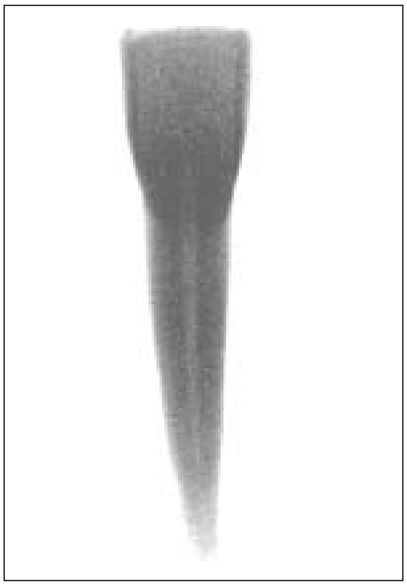
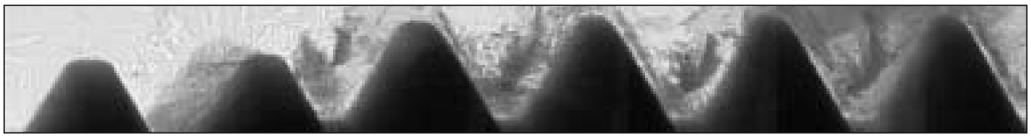
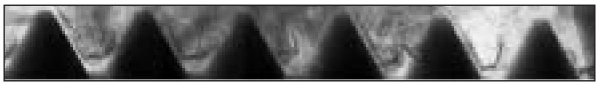


Fig 3c Radiographic image of a lateral incisor obtained with a dental radiograph system (original image was digitized with a scanner and inverted for comparison with the SR image).

910) and the skin was closed with silk sutures. To prevent infection, daily intramuscular injections of Cefazolin (250 mg, Yuhan) were given for 1 week. The rabbit was sacrificed after a 12-week period by intravenous injection of air into the ears. The fascia and periosteum were removed, and the implant was exposed. For preparation of the specimen, the tibia was removed and fixed with 70% alcohol to minimize deformation of the tissue specimen and the specimen was cut along the long axis of the implant. Then it was preserved and dyed in a Villanueva bone stain solution for 1 week. It was then dehydrated in 70%, 90%, and 95% alcohols (once each) and 100% alcohol (4 times) for 12 hours each and then embedded in methylmethacrylate resin and left in a thermoregulated vacuum at 37ºC for 40 days. After the slice had hardened, it was cut along the long axis of the implant by means of a low-speed diamond wheel saw (Maruto, Tokyo, Japan).

An osseointegrated titanium implant specimen (Figs 2a and 2b) and a lateral incisor (Figs 3a to 3c) were imaged with the PLS 5C1 SR imaging system. The quality of the images and apparent osseointegration of the titanium implant were compared with images obtained with a conventional dental radiography system (Siemens Heliodent MD, Munich, Germany) and a μCT system (1072 High-Resolution Desk-Top Microtomograph, SkyScan, Aartselaar, Belgium). The projection images of the μCT system were used for the purpose of comparison. The SR images of the lateral incisor and the osseointegrated titanium implant specimen were obtained in an exposure time of 80 ms and 1,000 ms, respectively, and were made up of multiple





Figs 4a *(above)* **and 4b** *(left)* Radiographs of the osseointegrated dental titanium implant specimen obtained with the PLS 5C1 SR imaging system.

Fig 4c Radiograph of small-input field of area shown in Fig 4b obtained with SR imaging system.

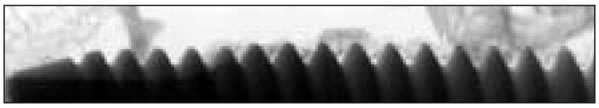


Fig 4d Radiograph of the implant specimen obtained with commercial µCT.

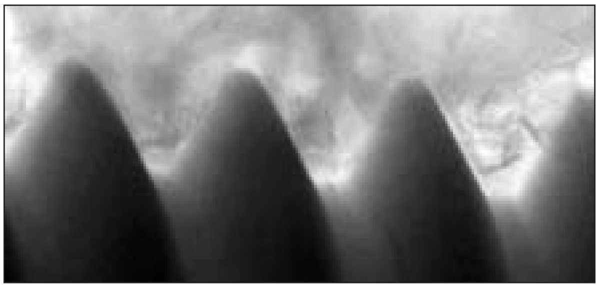


Fig 4e Radiograph of small-input field of area shown in Fig 4d obtained with µCT.

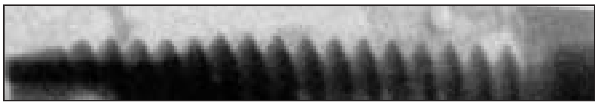


Fig 4f Radiograph of the implant obtained with conventional dental radiography.

small images patched together. The field of view (FOV) of each small mosaic image obtained with a 5× magnification lens was measured to 1.7×1.3 mm. The acquired images were processed for background subtraction, patching smaller individual images together by means of Image-Pro image analysis software (Version 4.1, Media Cybernetics Analytical Imaging Software, Silver Spring, MD). The µCT images of the lateral incisor and the osseointegrated titanium implant specimen were obtained with acquisition parameters of 80 kVp, 100 µAs, and an exposure time of 5.9 seconds at maximum magnification. The conventional dental radiographs of the lateral incisor and the osseointegrated titanium specimen were obtained with Kodak Ektaspeed Plus 1 Film (Rochester, NY) and acquisition parameters of 70 kVp, 7 mA, and exposure times of 0.06 and 0.05 seconds, respectively.

RESULTS

The radiographic images of the tooth specimen (lateral incisor) are shown in Figs 3a to 3c. The radiographic image of the tooth specimen obtained with the conventional dental x-ray system was scanned and digitized with a commercial scanner (Perfection 1200, Epson, Tokyo, Japan) and inverted to compare with the SR image and the µCT image. The SR image of the lateral incisor showed much greater detail that revealed anatomic structures inside the tooth. The image quality was definitely higher than that of the µCT and conventional dental radiographs.

The osseointegrated titanium implant specimen was also imaged by the PLS 5C1 SR imaging system (Figs 4a to 4c), the µCT system (Figs 4d and 4e), and conventional dental radiography (Fig 4f). SR images of the osseointegrated titanium implant specimen showed that bone tissue was anchoring the implant screw around its entire circumference. The SR image of the osseointegrated titanium implant also showed clear boundaries and much greater detail sufficient to indicate bone-to-metal contact between the titanium implant and surrounding bone. When the images from the commercial μCT system, which has about 10 μm spatial resolution, and the conventional dental radiography system were compared to those obtained by SR imaging, it is clear that the SR imaging system produced much higher quality images.

The SR imaging technique demonstrated the possibility for evaluating the extent of the interface between a titanium dental implant and its surrounding tissue. This information is important in evaluating the mechanical stability of implants in dental applications.

DISCUSSION

During the image acquisition of hard tissue such as a tooth specimen, the energy spectrum of the PLS 5C1 beam was modified to the high-energy region (6 to 16 keV) by using a series of silicon wafers (acted as a filter). Although a lateral incisor has no fine structures in itself, the SR image of the lateral incisor showed details that could not be observed with any other modality. The transmitted SR image of the osseointegrated titanium specimen showed similar aspects to a cross-sectional view of histologic examination obtained with a light microscope for a specimen stained with chemical agents.[4] The SR image of the osseointegrated titanium specimen showed a smaller bone contact ratio at the anterior surface of the titanium implant screw than its posterior surface in the progressive direction of the screw. This may have clinical significance, indicating that the bone contact ratio depends on the applied force or the shear/stress. The present approach using unmonochromatic SR shows imaging capability, even without sophisticated x-ray optics,[17–20] similar to that of a monochromatic x-ray beam with sophisticated x-ray optics.

Future study demands the quantitative evaluation of osseointegration, ie, bone-to-implant contact ratio. This has been done with bony contact measurements (followed by division of the outlining nonbony contact length by the outlining entire thread length) obtained using a specially developed computer software or a grid with parallel sampling lines at high magnifications.[6,7,21,22]

CONCLUSIONS

The results of this investigation show that the SR imaging technique may play an important role in the contact analysis related to the quality and quantity of an osseointegrated dental implant. Further investigations to evaluate the ratio of bone-to-implant contact are planned.

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